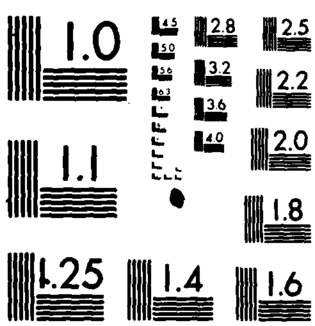
AD-A115 185 LOCKHEED-CALIFORNIA CO BURBANK F/G 11/4
ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC--ETC(U)
JUL 81 K N LAURAITIS, J T RYDER, D E PETTIT F33615-77-C-3084
UNCLASSIFIED LR-28360-19 AFWAL-TR-79-3095-VOL-3 NL

1 OF 5
AD A
115185

115/85



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

2

AFWAL-TR-79-3095
VOLUME III

ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANCED COMPOSITE STRUCTURES
VOLUME III - APPENDIXES TO REPORT FOR TASKS II AND III

K. N. Lauraitis
J. T. Ryder
D. E. Pettit

Lockheed-California Company

Burbank, California

July 1981
Final Report for 1 July 1979 to 29 May 1981

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

George P. Sendeckyj

GEORGE P. SENDECKYJ, Aerospace Engineer
Fatigue, Fracture & Reliability Group

Davey L. Smith

DAVEY L. SMITH, Chief
Structural Integrity Branch

FOR THE COMMANDER

Ralph L. Kuster

RALPH L. KUSTER, JR., Colonel, USAF
Structures & Dynamics Division
Flight Dynamics Laboratory

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIBEC, W-PAFB, OH 45433 to help us maintain a current mailing list".

AIR FORCE/56780/24 May 1982 — 430

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFWAL-TR-79-3095 Volume III	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Advanced Residual Strength Degradation Rate Modeling for Advanced Composite Structures	5. TYPE OF REPORT & PERIOD COVERED: Final Report 1 July 1979 to 29 May 1981
	6. PERFORMING ORG. REPORT NUMBER: LR 28360-19
7. AUTHOR(s): K. N. Lauraitis, J. T. Ryder, D. E. Pettit	8. CONTRACT OR GRANT NUMBER(s): F33615-77-C-3084
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Lockheed-California Company, Division of Lockheed Aircraft Corporation, Burbank, California 91520	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Project No. 2401, Work Unit 24010117
11. CONTROLLING OFFICE NAME AND ADDRESS: Flight Dynamics Laboratory, Air Force Wright Aeronautics Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433	12. REPORT DATE: July 1981
	13. NUMBER OF PAGES: 384
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

composites, graphite/epoxy, impact damage, damaged holes, fatigue, damage propagation, residual strength, NDI

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of the last two tasks of a three task program focusing on the study of relationship between damage propagation and residual strength of graphite/epoxy laminates. Specimens of two laminate types, a 32-ply quasi-isotropic and 24-ply 67%-0, containing a centered poorly drilled hole were evaluated in this study. Baseline static tension and compression tests were conducted at high and low strain rates and at elevated temperature. Compression tests were conducted for two restraint conditions, the full platen fatigue supports with 2.15 in. (55mm) window and 4-bar buckling supports.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

Continued on next page

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Stress vs. life (S-N) fatigue data were generated at a stress ratio of R = -1 for each of the damaged laminates. Twenty replicate specimens for each laminate were fatigue tested to failure at a single stress level (R = -1) with the damage growth for each specimen monitored a minimum of ten times during its life to determine the fatigue life and damage growth distributions and pertinent statistical parameters. Based on these results, five cycle levels were selected for the residual strength study. Twenty-three specimens of each laminate were inspected, cycled to one of the five preselected N values and Holscanned again. Three of the replicates were destructively analyzed while the other surviving specimens were tested in static tension or compression. This sequence was repeated for each of the five N values.

Results indicated significant reduction in initial static tension and compression strengths due to the damaged hole condition and a further decrease in strength at the higher loading rate with a larger drop in compression than in tension. Fatigue cycling of the 24-ply specimens at $\pm$ 35 ksi (241 MPa) (R =-1) produced data which were dispersed over more than two orders of magnitude while data scatter was slightly more than one order of magnitude for the 32-ply coupons tested at a stress level of $\pm$ 22 ksi (152 MPa). As expected from the life data, damage growth for the 32-ply specimens was more well-behaved than for the 24-ply. However, large scatter in damage size was evident for both laminates and so no useful relationship between damage size and life could be established. Residual static properties of either laminate were not adversely affected by R = -1 fatigue cycling up to the 80% probability of survival life. Slight but insignificant increases (6-11%) in tensile residual strength and similar decreases in compression were noted for the 32-ply laminate. Both tension and compression residual strength tended to increase slightly as the number of cycles completed increased for the 24-ply laminate. Residual strength could not be related to damage size, not only due to the data dispersion but also because no definitive change in residual strength was observed.

A limited test program was conducted to assess the effect of different fatigue and environmental test conditions on residual strength and damage growth. The variables evaluated were: A) Specimen restraint (4-bar support); B) stress ratio, R = -0.3; and C) elevated temperature, 180°F (82°C). The Case A loading produced lives which were within the scatter band of tests conducted with the platen supports and very similar damage growth and residual strength behavior. Under the R =-0.3 loading both laminates completed 2 million cycles without failure. Most notable was the change in damage development, especially for the 24-ply laminate for which essentially no growth in the width direction was evident with extensive growth in the length direction. This longitudinal damage growth reduced the notch acuity resulting in significant increases in tensile residual strength with increasing number of cycles completed. Damage growth for the 32-ply laminate at R = -0.3 was also greater in the length direction, but growth in both directions did occur. For Case C, there appeared to be an order of magnitude decrease in life due to the elevated temperature exposure during cycling with more rapid initial growth for the 24-ply laminate. The life of the 32-ply laminate appeared to be shortened also but not as severely.

PREFACE

This report has been issued in three volumes. Volume I details the work completed under Task I, Preliminary Screening. Volumes II and III encompass the last two tasks of the investigation into the delamination growth and residual strength behavior of initially damaged graphite/epoxy laminates. Volume II includes the results of Task II - Damage Growth and Residual Strength Degradation Prediction and Task III - Effect of Fatigue Loading/Environment Perturbations. The tabulated data for these tasks are available in this volume of appendixes, Volume III.

The work reported herein was accomplished under Contract F33615-77-C-3084, Project 2401, Work Unit 24010117, sponsored by the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433. Dr. G. P. Sendeckyj, AFWAL/FIBE, was the Air Force Program Monitor.

The program which was conducted by the Structures and Materials Department of the Lockheed-California Company, was directed by the Co-Principal Investigators, Ms. K. N. Lauraitis and Mr. D. E. Pettit of the Fatigue and Fracture Mechanics Laboratory. Analytical and conceptual assistance was provided by Dr. J. T. Ryder of the same laboratory. The support and contributions of the Materials Laboratory personnel, Mr. W. E. Krupp, Group Engineer, Mr. R. C. Young, Specimen Fabrication, Mr. S. Krystkowiak, Fractography, and the Fatigue and Fracture Mechanics Laboratory Personnel, Mr. J. M. Cox, Data Reduction, Mr. D. Diggs, Mr. P. Mohr, Mr. F. Pickel, Mr. W. Renslen, Mr. L. Silvas and Mr. C. Spratt in the area of Mechanical Testing are gratefully acknowledged.

TABLE OF CONTENTS

Volume I

TABLE OF CONTENTS - Continued

Volume I

TABLE OF CONTENTS - Continued

Volume I

TABLE OF CONTENTS - Continued

Volume I

TABLE OF CONTENTS - Continued

Volume I

TABLE OF CONTENTS

Volume II

TABLE OF CONTENTS - Continued

Volume II

TABLE OF CONTENTS - Continued

Volume II

TABLE OF CONTENTS - Continued

Volume II

TABLE OF CONTENTS

Volume III

LIST OF ILLUSTRATIONS

Volume I

LIST OF ILLUSTRATIONS - Continued

LIST OF ILLUSTRATIONS - Continued

Volume I

LIST OF ILLUSTRATIONS - Continued

Volume I

LIST OF ILLUSTRATIONS - Continued

Volume I

LIST OF ILLUSTRATIONS - Continued

Volume I

LIST OF ILLUSTRATIONS - Continued

Volume I

LIST OF ILLUSTRATIONS

Volume II

LIST OF ILLUSTRATIONS - continued

Volume II

LIST OF ILLUSTRATIONS - continued

Volume II

LIST OF ILLUSTRATIONS - continued

Volume II

LIST OF ILLUSTRATIONS - continued

Volume II

LIST OF ILLUSTRATIONS - continued

Volume II

LIST OF ILLUSTRATIONS - continued

Volume II

LIST OF ILLUSTRATIONS - continued

Volume II

LIST OF ILLUSTRATIONS - continued

LIST OF ILLUSTRATIONS - continued

LIST OF ILLUSTRATIONS - continued

LIST OF ILLUSTRATIONS - continued

LIST OF ILLUSTRATIONS - continued

LIST OF ILLUSTRATIONS - continued

LIST OF TABLES

Volume I

LIST OF TABLES - Continued

Volume I

LIST OF TABLES

Volume II

LIST OF TABLES - continued

Volume II

LIST OF TABLES - continued

Volume II

LIST OF TABLES - continued

Volume II

APPENDIX A

Quality Control Plan

QUALITY CONTROL PLAN

This Quality Control Plan has been prepared in compliance with the U. S. Air Force contract F33615-77-C-3084.

Manufacturing and quality assurance procedures will be applied to material and laminates, as described below, to ensure quality, uniformity and traceability of test specimens.

1. Material Acquisition

Narmco T300/5208 graphite/epoxy prepreg material conforming to Lockheed Material Specification C-22-1379/111 will be acquired for this program in three procurements. A new material batch will be obtained for each of Task I, II, and III. Other materials required for the fabrication of test laminates will be purchased to the requirements given in the Lockheed Engineering Purchasing Specification (EPS) Manual, to the extent indicated in Section 3. Fiberglass for the specimen tabs will be acquired to Lockheed Material Specification LCM C-22-1032/141.

2. Material Acceptance

The prepreg material supplier will be required to provide a certificate of conformance, including test data, resin/catalyst age, and date of mixing with each delivery. Lockheed Quality Assurance laboratories will then conduct acceptance tests on the delivered material in confirmation of supplier data. These tests will include:

- Uncured Properties
  - Fiber orientation
  - Resin content
  - Volatiles content
  - Resin flow
  - Gel time
  - Infrared Analysis
  - Areal Weight

- Mechanical and Physical Properties of Cured Material
  - Void Content
  - Specific Gravity
  - Cured Resin Content or Fiber Volume
  - Interlaminar Shear
  - Longitudinal Tensile Strength and Modulus
  - Longitudinal Flexural Strength and Modulus
  - Cured Ply Thickness

The test methods and acceptance limits shall be as specified in the applicable material specifications, C-22-1379/111 and C-22-1379A. Materials not conforming to the requirements of the Specifications will be rejected.

Material specifications further stipulate preparation-for-delivery provisions covering date of shipment, allowable time and temperature in transit, and vapor-tight packaging required for supplier and transporter conformance. Materials requiring refrigerated storage will be placed in Quality Assurance-approved refrigerators immediately upon receipt. Pending acceptance by the Quality Assurance laboratory, all materials will be kept segregated and with-held from use. After acceptance, each container, roll, or spool of material will be stamped or otherwise approved by Quality Assurance and controlling labels will be attached.

3. Material Processing

This section establishes the requirements and procedures for the lamination of graphite/epoxy (T300/5208) test panels, fabrication of glass/epoxy tab stock and bonding of tabs to coupons.

3.1 Applicable Documents and Materials

The following documents form a part of this procedure to the extent specified herein.

3.1.1 Lockheed Materials Specifications

Lockheed Material Specification, C-22-1379A Graphite Fiber Non-Woven Tape and Sheet, Resin Impregnated, General Specification for.

Lockheed Material Specification C-22-1379/111 Graphite Fiber Non-Woven Tape and Sheet, 350 ksi Strength, 33 MSI Modulus, 350°F Curing, Epoxy Preimpregnated.

Lockheed Material Specification LCM C-22-1032/141 Glass Fabric/Epoxy Pre-impregnated, 350°F Cure.

3.1.2 Commercial Materials

3.1.2.1 The following commercial materials, covered by the Lockheed Engineering Purchasing Specification (EPS) Manual, form a part of this procedure to the extent specified herein.

Material	EPS Item No.
Vacuum Bag Nylon Film	22.9001
Parting Agent Film	22.9004
Porous Release Cloth	22.9030
Peel Ply	25.5910
Stick Contact Adhesive	30.0650

3.1.2.2 The following commercial materials not covered by the Engineering Purchasing Specification Manual are required for use in this procedure.

American Cyanamid Co.	FM-400 Epoxy Adhesive Film, 0.07 lbs/ft^2, 350°F Cure
Air Tech International Inc.	Flashbreaker 5 Pressure Sensitive Tape

3.2 Material Control

All materials shall conform to the applicable specifications.

3.2.1 Storage and control requirements shall be as specified in Table A1. Refrigerated material shall be stored in sealed, moisture vapor proof containers.

3.2.2 Refrigerated materials shall be thawed until moisture no longer condenses on the moisture-proof containers.

3.2.3 All perishable materials shall have had validation tests performed within 30 days of use, if initial storage time limit has been exceeded. Validation tests are the same as those shown in Table A1.

3.2.4 A manufacturer's identified defects (MID's)record is furnished with each roll of Gr/Ep by the material supplier. This record shall be furnished to the Composites Laboratory with each roll of Gr/Ep.

3.2.5 Stored perishable material in which visible water is observed in the bag shall be rejected.

TABLE A1 - MATERIAL CONTROL

Material	Max. Storage Temp.	Maximum Storage Time Before Retesting, Day		Minimum Required Tests	Max. Allowed Out Time During Proc. @$75^{\circ}F$ & 55% R.H.
		Initial	Subsequent		
Gr/ep Prepreg	$0^{\circ}F$	180	60	△1 △2	14 days
Adhesive Film	$0^{\circ}F$	180	90	Climbing Drum Peel @ $-65^{\circ}F$	10 days

△1 Flow and gel time, room temp. flexural and short beam shear, specific gravity and resin content.

△2 See applicable Material Specifications for test methods and requirements.

3.3 <u>Environmental Control</u>

3.3.1 All work shall be done in controlled areas to avoid degradation of the materials and laminates. Temperature shall be between 65-80°F and relative humidity shall not exceed 55%.

3.3.2 All incoming air into controlled areas shall be filtered by at least a $1\frac{1}{2}$-inch thick throw-away type or permanent washable type filter or by an equivalent method. Inspect and clean filters monthly.

3.4 <u>Tooling</u>

3.4.1 All tools shall be designed and coordinated to produce parts that meet all requirements of this specification and the Engineering drawing. Tools shall have the minimum mass necessary for dimensional and thermal control.

3.4.2 All tool plates used for curing laminates shall be aluminum. Thickness of the caul plate shall be 0.500 in. with a tolerance of ± 0.003 in., flat and parallel. Caul plates used on top surface of laminate under the vacuum bag shall be aluminum sheet 0.064 in. standard thickness.

3.4.3 Tooling parting agents and cleaners shall not contaminate the laminates or interfere with subsequent bonding, finishing and inspection.

3.5 <u>Material Preparation</u>

3.5.1 Templates or patterns shall be placed on the prepreg in such a way as to ensure that the fiber direction is in accordance with Engineering drawing requirements and does not include any MID's flagged by the supplier (see 3.2.4)

3.5.2 Panels will be laid-up such that the edges of tape are parallel or perpendicular to the required fiber direction within 1°.

3.5.3 All areas from which material will be cut shall be checked prior to cutting for the defects defined in C-22-1379, Quality and Condition Requirements, which may not have been flagged by the manufacturer. Material containing unacceptable defects will not be used. Patch plies are not permitted.

3.5.4 Plies shall be cut with sufficient care so as not to disorient fibers. Cutting tools shall be cleaned prior to use on prepregs.

3.5.5 No ply end butt splices are permitted in the laminate assembly.

3.6 Tool Preparation

3.6.1 The tool molding surfaces shall be solvent wiped and all resin removed prior to layup.

3.7 Panel Lay-up

3.7.1 The preimpregnated graphite tape shall be placed on the tool in the sequence and orientation specified on the Engineering drawing or Engineering Test Request. As each ply is placed on the assembly, it shall be checked for the defects defined in C-22-1379 prior to applying the ply firmly in place. A check-off system shall be used to assure proper orientation and stacking sequence of each ply.

3.7.2 The surface of each ply shall be wiped with a teflon, polyethylene or equivalent device to give maximum adhesion to the previous ply. Wiping shall be done only in the direction of the fibers to prevent fiber separation and distortion. Wiping the surface should be done only when the orientation of the tape edge has been verified to be within $\pm 1^{\circ}$ of the drawing requirement. Excessive pressure shall not be applied during wiping and wiping shall be kept to a minimum.

3.7.3 Parallel plies shall be laid up so that edge splices are staggered a minimum of 1.0-inch in adjacent plies and not coincide within a 5 ply thickness.

3.7.4 Edge splices shall be butted flush, ± 0.03 inch.

3.7.5 Entrapped air in blisters that cannot be wiped out without distorting fibers shall be removed by puncturing the blister with a needle or pointed sharp blade as often as needed and wiping in the direction of the fibers toward the puncture. Care shall be taken not to damage the under ply fibers.

3.7.6 Where permanent edge steps or dams are not incorporated in the tool for edge thickness control, an edge dam shall be built around the perimeter of the laminate. The dam shall not be more than 0.06-inch from the laminate edge and shall be of sufficient height to enclose the laminate. The bleeder may not extend over the dam surface. Joints in the dam shall be kept to a minimum. Dam joint gaps shall not exceed 0.03-inch.

3.7.7 A dry peel ply of fabric (EPS 25.5910) or equivalent shall be placed on both sides of the layup and wiped smooth.

3.7.8 A bleeding and bagging system of the following construction shall be used.

(a) Cure plate
(b) Separator film - perforated parting agent film or porous release cloth.
(c) Mochburg CW1850 bleeder paper (1 ply for 4 plies of prepreg.)
(d) One ply of porous Teflon-coated glass cloth (DuPont Armalon)
(e) Nylon peel ply
(f) Graphite/epoxy laminate
(g) Nylon peel ply
(h) One ply Armalon
(i) Mochburg CW1850 bleeder paper (4:1 ratio)
(j) Release film
(k) Caul plate (aluminum)

(l) One ply Mochburg CW1850

(m) Release film

(n) Glass breather

(o) Nylon film vacuum bag placed over the laminate and sealed to the tool face.

3.7.9 Curing - Pressure and cure cycle should be within the limits given in Table A2.

TABLE A2 - CURE CYCLE

1.	Apply full vacuum
2.	Heat to 275° ± 5°F @ 2-3°F/min.
*3.	Dwell @275° ± 5°F for 30 ± 1 minutes
4.	Apply 100 ± 5 psi vent vacuum to air @20 psi.
5.	Heat to 355 ±5 °F @2-3°F/min.
6.	Cure for 120 ± 10 min. @ 355 ± 5°F.
7.	Cool to 140 ± 5°F under pressure @less than 4°F/min.
8.	Cool to room temperature.
	* NOTE: Dwell time started when temperature reaches 265°F.

3.8 Laminate Control Specimens

Each panel will be laid up to contain an excess strip at least one inch wide and running either the length or width of the panel. The strip must be located at least one inch from the panel edges.

3.8.1 Laminate control coupons will be cut from this strip for the determination of resin content, specific gravity and average ply thickness. Test requirements are given in Table A3.

3.8.1.1 Void volume fraction will also be measured on laminate control coupons from selected panels using standard metallographic techniques. This method will be used to confirm results calculated from the acid digestion and density measurement values.

TABLE A3 - TEST REQUIREMENTS

Test	Requirements
Fiber Volume	65 ± 2%
Specific Gravity	1.56 - 1.60
Thickness/Ply	.0046 - .0053 inch (Report for information only)

3.9 Workmanship

All laminated details and bonded assemblies shall be of highest quality. Conditions in excess of the following shall be cause for rejection.

3.9.1 There shall be no evidence of surface cracking, uncoated fibers, excess resin, pits, tackiness or other indications of defective resin characteristics or distribution.

3.9.2 No visual delaminations are allowed.

3.9.3 The laminate shall be essentially void free. Calculated voids shall not exceed 1.0 volume percent without special engineering review.

3.9.4 Wrinkles

3.9.4.1 No wrinkles containing graphite fibers are permitted. Resin wrinkles caused by peel ply gathering or by the bleeder system shall not be cause for rejection if the resin ridge can be removed without damaging the graphite fibers using 320 grit or finer sandpaper.

3.9.5 The presence of foreign material, e.g., separator film, masking tape, etc., in the part is not acceptable.

3.9.6 There shall be no sharp or frayed edges, nor edge delaminations resulting from trimming and routing operations.

3.10 Cleanup

Chemical strippers shall not be used in any way to remove excess resin or adhesive. If removal is necessary, it shall be done with an abrasive, and shall not damage any surface graphite fibers.

3.11 Records

The following records are required for permanent retention and traceability.

1. Temperature-pressure-vent-time profile record for each cure cycle.
2. Thermocouple locations.
3. Material batch and roll number, acceptance laboratory report number and cumulative out-time up to the time of vacuum application.
4. A completed autoclave record sheet as shown in Figure A1.

3.12 Machining of Test Specimens

Specimens are to be machined using aluminum backup sheets to the dimension shown in Figure A2, Drawing TL 1038. Specimen cuts will be made parallel to the panel edge to ± 1 degree. Cutting rates will be chosen to minimize edge damage. Specimen dimensional tolerances and inspection requirements are given in the Task I Test Plan. All specimen shall be weighed and the weight recorded on the specimen checklist form following fabrication.

3.13 Fabrication and Bonding of Glass Fabric/Epoxy Grip Tabs

3.13.1 Grip tab sheet material shall be fabricated by laminating the required number of plies of Style 181, 1581, or 7581 glass fabric/epoxy prepreg. For most standard coupons, the laminate consists of 6 plies or 3 plies in thickness depending on the type of coupon. Thicknesses and other dimensions shall be in accordance with Lockheed Drawing No. TL 1038. Tab dimensions shall be as specified on specimen drawing.

Figure A1: Sample Autoclave Record Run # ______

ETR/Dwg.# ______________ Panel I.D. ______________ Matl. Code ______________

Q.A. Lab. Report #______________ Made for ______________ Date ______________

I. Description of Materials

Designation ____________________ Batch# ________ Roll# ________ Date Mfd. ________

No. of Plies ________ Orientation ____________________

II. Cure Press. ________ psi

Cure Temp ________ °F

Cure Time ________ min.

Vac. Bag ________ inch-Hg

CURE CYCLE (NARMCO)

1. Apply fuel vacuum
2. Heat to 275° ± 5°F @ 2-3°F/min.
*3. Dwell @275° ± 5°F for 30 ± 1 min.
4. Apply 100 ± 5 psi & vent vac to air @ 20 psi.
5. Heat to 355 ± 5°F @ 2-3°F/min.
6. Cure 120 $^{+10}_{-0}$ min. @ 355 ± 5°F
7. Cool to 140 ± 5°F under press. @<4°F/min.
8. Cool to R.T.

* NOTE: dwell time starts when temp reaches 265°F.

III. Autoclave Pressurization

Time @ start ________

Time @ press. ________

Delta Time min. ________

IV. Temp ________ °

V. Temp ________ °F @ lay-up

V. %R.H. ________ @ lay-up

VI. TIME RECORD

	1 Temp	1 Time	2 Temp	2 Time	3 Temp	3 Time	4 Temp	4 Time	5 Temp	5 Time
Start heat										
At temp.										
Time to temp min.										
Time @ temp min.										
Heat-up rate°F/min.										
Cool-down rate°F/min.										

OFF ____

VI. Panels

I.D.	Size(in.) ___x___	No. Plies	Meas. Thick

VIII. Bleeding & Bagging

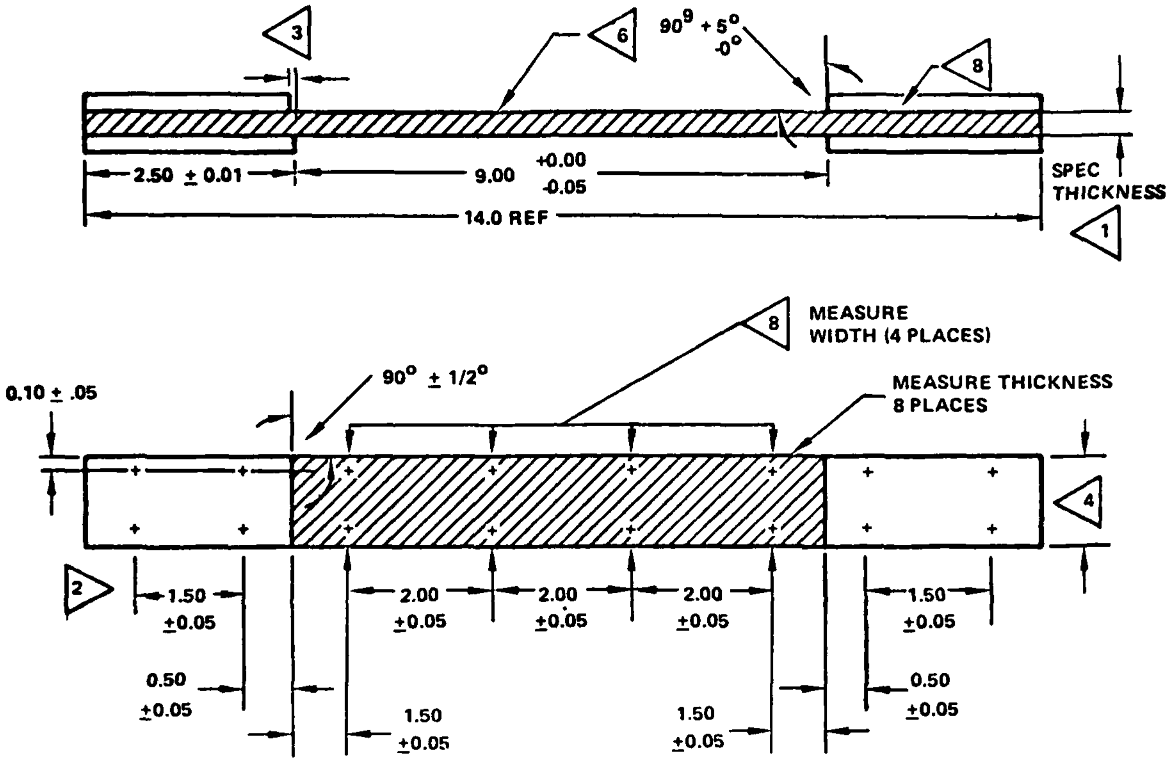
________ nylon bag
________ 181 glass breather
________ vac pac
________ Mochburg (1 ply)
________ caul plate
________ vac pac
________ Mochburg (4:1 ratio)
________ armalon
________ nylon peel ply
________ LAMINATE
________ nylon peel ply
________ armalon
________ Mochburg
________ vac pac
________ cure plate

NOTE: Laminate completely dammed perforated vac pac taped to dam.

IX. Comments

Signature of Inspecting Engineer

____



9 SPECIMENS TO BE FLAT OVER THE ENTIRE 14.0 INCH LENGTH WITHIN 0.01 INCHES.

8 TAB EDGES TO BE PARALLEL TO SIDES OF SPECIMEN WITHIN 0.02 INCHES. OVERHANG NOT TO EXCEED 0.15

7 THE TAB AND SPECIMEN BONDING SURFACES TO BE THOROUGHLY SOLVENT CLEANED USING METHYL-ETHYL-KETONE PRIOR TO BONDING. A 350°F CURING ADHESIVE IS TO BE USED AND MUST COVER ENTIRE SURFACE UNIFORMLY'

6 WATER SPRAY MIST TO BE USED DURING SAWING OPERATIONS AND SOLUBLE OIL DURING GRINDING. MACHINED SURFACES TO BE RMS 50 OR BETTER. NO EDGE DAMAGE OR FIBER SEPARATION SHOULD BE VISIBLE

5 MEASURE SPECIMEN WIDTH 4 PLACES. WIDTH MUST NOT VARY BY MORE THAN 0.004 INCHES.

4 SPECIMEN WIDTH TO BE $3.00^{+0.00}_{-0.02}$ INCHES.

3 MISMATCH OF TABS FROM SIDE TO SIDE NOT TO EXCEED 0.01 INCHES.

2 TABS TO BE CUT FROM AN 6 PLY LAMINATE FABRICATED FROM PREPREG OF 1581 GLASS FABRIC IN A 350°F CURING EPOXY. TAB PLUS ADHESIVE THICKNESS MUST NOT VARY SIDE TO SIDE OR END TO END BY MORE THAN 0.01 INCH AS MEASURED 8 PLACES.

1 SPECIMEN THICKNESS TO BE WITHIN ±0.003 INCHES OF THE AVERAGE OF 8 THICKNESS MEASUREMENTS.

FIGURE A2: **3-INCH WIDE SPECIMEN CONFIGURATION, DRAWING TL1038**

3.13.2 The material used for grip tab stock shall be glass/epoxy prepreg conforming to Lockheed Material Spec. LCM C-22-1032/141. This material shall be cured at 350°F for one hour under a pressure of 35 psi plus vacuum. A caul sheet shall be used under a vacuum bag for pressure application.

3.13.3 The adhesive used for bonding tabs to coupons shall be American Cyanamid Co. FM-400, 0.07 lbs/ft^2. Aluminum caul plates $\frac{1}{4}$ to $\frac{1}{2}$-inch thick shall be used to apply bonding pressure on tabs. Cure adhesive at 350°F $\pm$ 5°F for 60 to 70 minutes using 15 $\pm$ 1 psi positive pressure on bondline (no vacuum). Cool to 170°F under pressure.

4. QUALITY ASSURANCE PROVISIONS

To produce test panels of consistent quality, strict adherence to all the minimum Engineering requirements of Section 3 is vital. The requirements of Section 4 are intended to outline the minimum amount of inspection and surveillance before, during, and after processing testing to confirm that adherence has been achieved.

4.1 Material

Verification shall be made that only adhesives and prepreg materials are used that are approved to the material specifications specified.

4.1.1 Adhesive or prepreg material which is stored below room temperature shall be wrapped in a closed impermeable bag at all times. Evidence of material cracking or moisture condensation on the material is cause for rejection. Exposure to ambient temperature shall be minimized.

4.1.1.1 Adhesive or prepreg material which is withdrawn from storage and left out 30 minutes or more before returning to the box, shall have the out-time marked on an appropriate tag attached to the roll. Material for which accumulated out-time at ambient temperature exceeds the allowable out-time given in Table A1, shall not be used.

4.1.2 All adhesive and prepreg materials shall be controlled as to batch, lot, and roll numbers for traceability.

4.1.2.1 Material which has exceeded the allowable storage shall not be used unless tested within one week prior to use.

4.1.2.2 All refrigerated materials shall be checked for compliance to 3.2.2 prior to use.

4.2 Panels and coupons shall be clearly marked before and after application of tabs to indicate the bag side of the graphite/epoxy laminate as originally cured. Panels shall be identified with a number including material code and autoclave run number. Coupons shall be identified with panel number from which cut and a dash number indicating location.

Example: 1LY 556-1A

Coupons shall be numbered consecutively as they are cut from panels to indicate relative location in the panel.

4.3 Equipment and Facilities Control

Equipment and facilities used for materials storage, processing, and inspection shall be controlled in accordance with LCP79-1053.

4.4 An effective quality control system shall be provided to ensure compliance with the requirements of this procedure as specified in the following sections.

4.4.1 Material Acceptance testing will be performed by Lockheed Quality Assurance Laboratories.

4.4.2 Panel and tab fabricating and tab bonding will be accomplished by personnel of the Composites Laboratory at Rye Canyon Research Laboratories. Layup and cure of each panel will be witnessed and inspected by Engineering.

4.4.3 Specimens will be machined to required dimensional tolerances by machinists at the Rye Canyon Shops. Dimensional inspection of specimens will be the responsibility of Lockheed Quality Assurance.

4.4.4 The principal investigator will have final acceptance/rejection authority for material, panels and specimens.

4.4.5 An engineering approved autoclave record will be maintained for each panel.

4.4.6 A Quality Assurance specimen checklist such as shown in Figure A3 shall be completed for each specimen verifying its conformance with the requirements of the Quality Assurance Plan and Test Plans.

4.5 Non-Destructive Inspection

4.5.1 All test panels shall be non-destructively inspected for internal defects by ultrasonic "C" Scan procedure. Standard reference 2 mil thick teflon pads of 1/8-inch to 1/4-inch diameter will be placed at one corner of each panel. A permanent record of the C-Scan results shall be retained with the records required in 3.11.

4.5.1.1 Specimens will not be cut from areas in the panels which show indications comparable to the standards.

4.5.2 Location and size of holes and intentionally induced defects will be measured by Engineering based on Holosonics Series 400 Holoscan results.

Figure A3. Sample Specimen Checklist

Date: ______________

Specimen No. ______________________ Laminate Type ______________________

No. of Plies ______________________ Required Orientation ______________________

Acc.	Rej.	Measured	Req'd	Date	Spec. Wt.
☐	☐	1. % Fiber Vol. ________	65 ± 2%	________	________
☐	☐	2. % Resin Vol. ________	35 ± 2%	________	________
☐	☐	3. % Void Cont. ________		________	________
☐	☐	a. by density ________	≤ 1%	________	________
☐	☐	b. by metallography ________	≤ 1%	________	________

☐ ☐ Specimen Thickness: ____________ ____________ ____________

☐ ☐ Avg. Thk. __________ Max. Deviation __________ Req'd Dev.: ±0.003

☐ ☐ Specimen Width ________ ________ ________ ________

☐ ☐ Avg. Width __________ Max. Deviation __________ Req'd Avg: $300 \pm {}^{0.00}_{0.02}$,

Dev: ± 0.002

☐ ☐ Tab Mismatch ______________ Req'd: less than 0.01 in.

☐ ☐ Tab parallelism ______________ Req'd: within 0.02 inches

☐ ☐ Tab overhang ______________ Req'd: less than 0.15 inches

☐ ☐ Edge damage or fiber separation ______________________________

____

________ gm. Specimen weight following fabrication.

__________ Date weight measured.

APPENDIX B

Specimen Weight Measurements

TABLE B1
WEIGHT MEASUREMENTS[a] FOR
FATIGUE LIFE DISTRIBUTION SPECIMENS - TASK II

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
HC-26	187.2	186.8	MB-17	231.9	232.5
IB-13	191.2	190.5	QA-8	234.1	233.1
CC-25	190.4	-	LC-30	230.7	232.0
DA-6	190.2	189.8	JC-24	229.9	231.1
AC-30	191.4	-	SA-6	230.1	230.0
BC-29	192.4	191.8	PA-5	231.8	230.3
FA-3	191.7	192.5	SC-30	228.9	231.3
AA-2	191.1	191.1	KC-23	233.1	231.1
EA-6	189.4	189.7	NA-3	235.4	231.9
HC-27	188.3	188.3	MC-27	232.4	231.2
IC-25	190.0	189.5	RA-8	232.8	231.6
CA-1	191.9	192.0	QC-29	234.1	233.2
BB-17	191.1	191.2	LC-24	231.3	230.6
DC-30	190.6	190.6	PB-19	233.0	233.5
GC-27	183.3	183.4	JA-1	229.4	233.2
EB-16	191.9	190.5	SC-24	228.6	229.2
AB-15	191.5	192.9	JA-6	235.5	234.5
IB-19	191.7	191.3	PC-23	231.5	231.2
DC-28	191.6	190.9	LA-6	230.4	231.9
FC-23	192.3	103.1	RB-14	228.6	232.3

a = Listed in order tested.

TABLE B2
WEIGHT MEASUREMENTS[a] FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N_5
TASK II

24-PLY N_5 = 40,000 CYCLES			32-PLY N_5 = 28,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
GA-9	187.6	188.8	KA-5	233.3	233.3
BC-25	189.4	190.9	PB-13	234.6	232.0
HB-3	188.7	b	RA-5	231.8	231.6
CB-19	192.3	192.5	JC-23	230.7	231.5
DC-26	190.7	b	MA-4	230.8	232.4
GA-3	189.9	b	PB-12	232.6	233.2
FC-27	194.5	193.2	NB-14	230.8	234.3
HC-30	188.8	187.6	QC-31	233.3	232.7
BC-26	189.9	b	SB-18	233.1	232.3
EB-15	190.2	b	KB-14	231.4	232.1
CA-3	190.8	b	LC-26	232.2	233.2
CC-27	190.0	190.6	PA-7	232.6	232.8
AA-8	187.6	b	SB-17	231.4	230.5
DB-13	191.2	b	JB-18	233.2	233.8
IB-16	193.2	191.8	RC-25	231.9	232.1
CC-24	190.6	192.0	LB-19	233.4	232.3
AC-26	193.2	193.7	NB-18	233.5	234.5
FA-7	194.8	b	RC-31	231.2	232.2
GA-1	183.4	b	MB-15	234.6	233.6
EA-9	188.3	189.5	KB-17	230.9	232.0
GB-15	191.1	191.1			

a = Listed in order tested
b = Failed in fatigue

TABLE B3
WEIGHT MEASUREMENTS[a] FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N_4
TASK II

24-PLY N_4 = 20,000 CYCLES | 32-PLY N_4 = 20,000 CYCLES

Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
BC-28	192.1	b	NB-17	232.5	233.5
HC-29	187.4	b	JB-15	231.4	233.1
AC-25	191.6	185.3	QC-30	230.1	232.2
HB-12	189.7	b	LA-5	232.4	232.0
GC-24	190.6	188.9	MB-18	229.5	231.8
BA-8	189.1	b	SC-23	232.1	231.0
FB-15	193.4	190.9	RC-24	230.3	230.9
EC-26	190.7	b	LA-4	231.4	230.0
IB-14	190.2	b	MB-13	231.8	232.8
CB-17	191.8	191.0	KB-12	232.0	231.3
CA-9	187.5	b	NA-6	232.4	233.4
GC-25	198.2	198.4	RC-22	229.7	231.3
AA-3	191.5	192.8	PB-17	234.4	233.2
BB-14	192.2	192.7	SA-9	234.3	b
DB-14	192.4	190.3	JB-11	234.5	234.7
FA-2	190.4	191.6	QC-22	232.5	232.0
FC-29	190.6	191.7	SC-27	230.2	230.4
EB-17	188.8	b	LC-31	233.2	230.0
AB-17	188.7	b	MB-11	229.1	230.0
CA-4	194.4	b	QB-13	233.4	232.7
BC-22	190.8	b	RA-7	231.5	231.7

a = Listed in order tested
b = Failed in fatigue

TABLE B4
WEIGHT MEASUREMENTS[a] FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N_3
TASK II

24-PLY N_3 = 12,000 CYCLES			32-PLY N_3 = 10,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
DB-15	188.9	189.7	SA-5	230.9	231.9
AC-27	191.5	192.3	PA-4	235.3	234.8
DA-10	185.4	187.6	LA-7	231.2	231.8
BC-21	192.0	191.3	PA-1	230.5	233.1
FB-18	188.6	b	NB-16	231.4	235.6
CA-6	187.7	b	KA-7	235.1	232.9
IA-2	189.6	189.8	MC-29	231.0	231.5
EA-4	191.1	b	QB-12	231.8	231.6
GB-18	190.4	189.3	RB-12	231.2	231.7
HB-9	190.7	b	LC-27	231.6	234.5
DA-2	190.5	b	SA-3	232.3	231.7
AA-5	192.0	192.8	JC-28	233.1	233.2
CB-14	189.9	189.9	NB-13	231.8	233.4
HC-21	189.1	188.6	KC-22	230.2	233.4
GA-5	189.9	189.6	MC-25	232.0	232.5
IA-6	190.9	190.0	LC-23	229.7	233.6
FA-1	189.6	190.1	SB-11	230.4	230.6
BB-19	191.6	191.3	QC-23	231.8	234.4
IA-8	190.9	190.5	JC-27	233.6	235.5
CA-2	189.7	192.4	PC-27	232.3	234.5
HA-6	187.8	188.0			

a = Listed in order tested
b = Failed in fatigue

TABLE B5
WEIGHT MEASUREMENTS[a] FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N_2
T'SK II

24-PLY N_2 = 8,000 CYCLES			32-PLY N_2 = 5,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
FC-26	193.3	193.2	MB-16	231.6	232.9
DC-29	189.5	190.6	NC-26	234.6	234.0
AA-9	189.9	b	KC-28	232.5	232.1
BC-30	191.5	191.6	QA-1	230.8	231.8
GC-22	187.8	186.9	JA-4	231.3	233.2
AA-7	192.6	192.2	QA-9	232.7	234.2
IB-15	190.7	190.9	SB-13	230.0	232.1
FB-11	192.0	191.8	NC-22	230.2	233.5
CB-16	192.1	191.2	KB-16	232.9	233.7
EC-24	188.3	188.8	LA-2	229.2	233.2
BB-12	192.1	b	PB-15	233.6	230.8
DA-5	190.9	189.9	RB-20	228.7	229.6
GA-6	189.7	189.4	MA-6	232.4	231.6
HB-16	191.2	190.3	RC-27	229.1	232.9
DB-18	188.8	188.7	JA-5	235.4	234.5
HB-15	192.1	b	LB-16	231.3	235.1
BA-6	190.4	b	KC-24	228.8	230.2
CB-12	189.2	189.8	PC-25	230.2	232.1
AC-24	191.3	192.8	NA-2	233.1	233.0
EA-5	188.3	188.7	QC-28	232.2	233.1
EC-29	188.1	188.0			
IC-27	188.8	190.4			

a = Listed in order tested
b = Failed in fatigue

TABLE B6
WEIGHT MEASUREMENTS[a] FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N_1
TASK II

24-PLY N_1 = 4,000 CYCLES			32-PLY N_1 = 1,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
EA-7	187.1	189.2	LA-9	229.8	231.1
HC-24	188.6	190.2	QA-6	232.8	234.0
CC-23	190.3	191.9	NA-4	233.7	234.1
GB-16	190.2	191.6	SB-19	229.1	231.5
FC-25	193.8	194.5	MA-8	230.7	232.1
BA-9	187.8	189.5	KC-27	230.2	232.1
DA-3	191.2	192.4	JB-13	232.6	234.1
AB-13	188.3	191.3	PA-3	232.4	232.9
IA-1	190.1	189.7	MC-28	232.6	230.8
EC-27	189.5	190.1	SA-7	230.1	232.4
FC-24	191.8	193.6	PA-9	232.8	232.3
GA-4	187.8	190.5	QB-17	231.4	231.7
BA-1	186.8	188.9	NC-30	232.7	233.6
EC-25	190.6	191.9	RA-2	233.9	232.4
DC-22	186.4	189.7	RA-9	233.9	232.7
AC-29	192.1	193.4	JC-22	230.8	231.3
HA-7	188.6	190.3	LA-3	230.1	234.4
AB-14	191.4	193.4	NC-28	230.5	232.4
HA-2	189.1	190.2	JB-16	232.6	233.4
FB-19	190.2	191.4	KB-18	232.4	233.7

a = Listed in order tested

TABLE B7
WEIGHT MEASUREMENTS[a] FOR
FATIGUE LIFE DISTRIBUTION SPECIMENS - TASK III

24-PLY N_4 = 20,000 CYCLES			32-PLY N_4 = 20,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
FATIGUE CONDITION A - 4 BAR SUPPORT					
AA-8	192.2	192.6	DC-27	238.0	237.3
BC-23	193.6	193.2	EB-18	236.2	236.7
CA-6	197.9	197.7	FA-3	232.7	230.5
			FA-8	232.3	233.7
FATIGUE CONDITION B - R = -0.3					
BC-24	195.9	194.6	FC-30	232.3	232.4
CC-27	190.7	191.6	EA-8	235.0	-
AB-11	190.9	190.6	DC-31	237.7	238.0
FATIGUE CONDITION C - 180°F (82°C)					
BB-12	191.2	193.4	FB-19	233.0	233.5
CA-4	199.3	199.6	DC-28	234.6	233.6
AA-4	190.6	192.2	EB-15	236.1	337.0

TABLE B8
WEIGHT MEASUREMENTS[a] FOR SPECIMENS TESTED FOR
RESIDUAL STRENGTH AFTER FATIGUE CYCLING UNDER CONDITION A[b]
TASK III

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
	N_1 = 4,000 CYCLES			N_1 = 1,000 CYCLES	
BA-7	191.9	191.8	DB-13	235.7	236.3
AB-14	190.4	192.2	EA-1	239.4	230.6
CA-9	189.5	191.1	FC-28	236.6	234.9
CA-2	190.4	191.0	FC-23	233.3	233.0
AC-26	190.6	191.6	EC-22	235.8	231.9
BC-27	196.7	198.0	DC-26	239.2	238.2
	N_2 = 8,000 CYCLES			N_2 = 10,000 CYCLES	
CC-29	190.8	192.5	SC-23	237.4	237.6
BA-4	191.0	190.6	FB-14	231.5	231.4
AB-16	192.1	192.2	EB-17	237.1	236.2
CA-10	191.9	191.1	FA-10	233.7	231.8
CA-7	192.4	191.0	EA-7	237.0	233.8
AB-19	191.5	191.1	DB-18	235.6	234.2
	N_3 = 12,000 CYCLES			N_3 = 20,000 CYCLES	
BB-11	192.6	192.6	DB-11	237.5	236.8
CC-21	191.0	191.5	FA-1	238.0	237.1
AA-7	193.6	190.7	EB-20	237.5	236.2
AC-31	195.8	197.4	DA-3	235.7	236.6
CC-26	190.8	190.2	EC-23	236.0	233.7
BB-13	196.5	196.5	FA-2	232.4	231.1

a = Listed in order tested
b = See Table XXXV, Volume II

TABLE B9
WEIGHT MEASUREMENTS[a] FOR SPECIMENS TESTED FOR
RESIDUAL STRENGTH AFTER FATIGUE CYCLING UNDER CONDITION B[b]
TASK III

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
	N_1 = 4,000 CYCLES			N_1 = 20,000 CYCLES	
BC-25	193.2	193.3	EA-6	235.9	235.5
AB-12	190.5	191.2	ec-27	238.5	237.0
CC-28	190.5	189.8	DA-5	240.8	242.3
AC-25	190.5	190.9	DA-3	235.7	236.6
BC-22	193.2	193.5	EC-23	236.0	233.7
CB-16	190.6	190.7	FA-2	232.4	231.1
	N_2 = 40,000 CYCLES			N_2 = 250,000 CYCLES	
AB-20	190.3	189.5	EC-21	236.7	236.9
CA-3	191.5	190.5	FC-29	239.7	237.2
BB-19	193.5	193.1	DA-8	240.5	239.5
BB-15	192.3	191.0	EA-9	236.7	235.9
CB-13	190.0	190.0	DC-30	233.3	233.6
AA-10	190.9	189.5	FA-7	235.5	233.1
	N_3 = 250,000 CYCLES			$N_3 = 10^6$	
BA-10	194.0	193.1	EB-16	235.0	-
AC-24	191.8	-	DB-14	235.6	234.5
CB-15	190.2	189.0	FB-13	234.3	232.3
AB-15	191.3	192.3	DB-15	237.4	238.4
CB-11	190.4	-	EC-31	239.6	242.2
BC-31	195.5	195.3	FB-20	233.6	233.9

a = Listed in order tested
b = See Table XXXV, Volume II

TABLE B10
WEIGHT MEASUREMENTS[a] FOR SPECIMENS TESTED FOR
RESIDUAL STRENGTH AFTER FATIGUE CYCLING UNDER CONDITION C
TASK III

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
	N_1 = 50 CYCLES			N_1 = 1,000 CYCLES	
AA-3	191.2	191.5	EB-19	235.6	235.2
BB-20	192.8	193.9	FB-15	233.7	233.6
CB-19	191.6	191.8	DB-12	238.5	237.3
BC-28	198.6	198.4	EB-12	237.4	237.8
AC-23	190.5	190.6	FC-21	237.5	238.6
CB-14	190.3	190.7	DC-22	234.8	236.0
	N_2 = 300 CYCLES			N_2 = 4,000 CYCLES	
AB-13	191.6	191.3	DA-1	234.9	235.1
BB-14	197.1	196.8	EC-29	235.4	235.5
CA-5	199.9	200.0	FA-6	234.4	232.3
CC-30	190.1	189.1	FA-5	232.3	232.5
BB-17	197.1	197.4	EC-28	232.8	232.1
AA-5	191.6	191.3	DB-20	236.1	237.0
	N_3 = 1,000 CYCLES			N_3 = 8,000 CYCLES	
CB-20	192.4	192.2	DA-10	240.9	241.5
AA-6	190.7	191.1	EC-27	240.8	242.3
BB-16	197.4	196.5	FC-22	233.1	232.6
AC-30	188.8	188.8	DB-16	238.0	237.1
CB-18	190.0	189.1	EA-5	234.8	233.9
BA-9	191.4	190.0	F-11	230.9	232.6

a = Listed in order tested
b = See Table XXXV, Volume II

APPENDIX C

Static Test Data

TABLE C1

TENSION TEST RESULTS FOR 24-PLY 67% 0° FIBER T300/5208 UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS TASK II

Specimen ID	Average Area, A		Ultimate Load, P_{ult}		Ultimate Stress, σ_{ult}		Ultimate Strain, ϵ_{ult} in 1 inch (25 mm)	Apparent Modulus of Elasticity E_a		Failure Location Distance from Tab	
	$inch^2$	mm^2	kips	kN	ksi	MPa	(in./in) mm/mm	$psi \cdot 10^6$	GPa	inch	mm
1WI-1406-DA	0.1208	77.9	19.7	87.6	163.3	1126	0.0106	15.1	104	0	0
1WI-1406-DB	0.1208	77.9	18.8	83.6	155.8	1074	0.0102	15.0	103	0	0
1WI-1408-EA	0.1201	77.5	20.4	90.7	169.7	1170	0.0110	15.1	104	0	0
1WI-1408-EB	0.1207	77.9	19.9	88.5	164.9	1137	0.0105	15.2	105	0	0
2WI-1408-BA	0.1201	77.5	20.0	89.0	166.1	1145	0.0107	15.1	104	3.3	84
2WI-1408-BB	0.1203	77.6	18.3	81.4	152.1	1049	0.0097	15.6	108	0	0
2WI-1436-AA	0.1216	78.5	19.7	87.6	161.6	1114	0.0106	14.7	101	0	0
2WI-1436-AB	0.1218	78.6	18.2	81.0	149.4	1030	0.0095	15.0	103	0	0
1WI-1438-CA	0.1203	77.6	18.2	81.0	151.3	1043	0.0097	15.3	105	0	0
1WI-1438-CB	0.1211	78.1	20.0	89.0	164.9	1136	0.0106	15.3	105	3.3	84
2WI-1438-FA	0.1205	77.7	20.4	90.7	168.9	1165	0.0109	15.0	103	0	0
2WI-1438-FB	0.1206	77.8	20.9	93.0	173.3	1195	0.0110	15.2	105	1.0	25
1WI-1440-GA	0.1213	78.3	21.3	94.7	175.6	1211	0.0110	15.8	109	0	0
1WI-1440-GB	0.1218	78.6	19.7	87.6	162.0	1117	0.0103	15.5	107	0	0
2WI-1440-HA	0.1212	78.2	20.2	89.9	166.3	1147	0.0110	14.7	101	3.3	84
2WI-1440-HB	0.1209	78.0	19.1	85.0	157.6	1087	0.0100	15.1	104	0	0
1WI-1441-IA	0.1223	78.9	20.3	90.3	166.0	1145	0.0101	16.1	111	0	0
1WI-1441-IB	0.1227	79.2	20.8	92.5	169.5	1169	0.0110	14.8	102	0	0
			Mean		163.2	1125	0.0105	15.2	105		
			Std. Dev.		7.5	52	0.0005	0.4	3		
			Coef. of Var. %		4.6	32	4.8	2.4	17		

TABLE C2

TENSION TEST RESULTS FOR 32-PLY QUASI-ISOTROPIC T300/5208 UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS
TASK II

Specimen ID	Average Area, A		Ultimate Load, P_{ult}		Ultimate Stress, σ_{ult}		Ultimate Strain ϵ_{ult}, in 1 inch (25 mm)	Slope Deviation Stress, σ_y		Slope Deviation Strain, ϵ_y, in 1 inch (25.4 mm)	Initial Apparent Modulus, E_1		Secondary Apparent Modulus, E_2		Failure Location Distance from Tab	
	inch^2	mm^2	kip	kN	ksi	MPa	in./in.(mm/mm)	ksi	MPa	in./in.(mm/mm)	psi$\cdot 10^6$	GPa	psi$\cdot 10^6$	GPa	inch	mm
1WI-1411-JA	0.1621	105	13.2	58.7	81.4	561	0.0110	54.8	378	0.0070	7.7	53	6.68	46	1.0	25
1WI-1411-JB	0.1618	104	12.5	55.6	77.0	531	0.0100	51.5	355	0.0066	7.7	53	6.96	48	2.5	64
2WI-1411-KA	0.1598	103	12.5	55.6	78.2	539	0.0105	51.3	354	0.0065	8.0	55	6.83	47	2.3	58
2WI-1411-KB	0.1614	104	12.4	55.2	76.8	530	0.0102	51.1	352	0.0063	7.9	54	6.73	46	0.5	13
1WI-1429-LA	0.1618	104	12.3	54.7	75.7	522	0.0098	51.8	357	0.0064	8.1	56	6.93	48	2.0	51
1WI-1429-LB	0.1600	104	11.9	52.9	74.1	511	0.0094	51.4	354	0.0062	8.3	57	6.78	47	0.3	8
2WI-1429-MA	0.1582	102	13.1	58.3	82.8	571	0.0105	52.1	359	0.0062	8.3	57	7.02	48	1.3	33
2WI-1429-MB	0.1587	102	13.4	59.6	84.1	580	0.0109	48.0	331	0.0058	8.4	58	6.91	48	1.0	25
1WI-1431-NA	0.1596	103	12.6	56.0	78.6	542	0.0102	53.6	370	0.0066	8.1	56	6.81	47	2.5	64
1WI-1431-NB	0.1606	104	12.3	54.7	76.3	526	0.0099	49.0	338	0.0061	8.1	56	7.08	49	0.8	20
2WI-1431-PA	0.1595	103	12.3	54.7	77.1	532	0.0098	52.5	362	0.0064	8.3	57	6.87	47	2.5	64
2WI-1431-PB	0.1597	103	12.6	56.0	79.0	545	0.0104	52.9	365	0.0066	8.2	56	6.66	46	2.0	51
1WI-1435-QA	0.1614	104	12.1	53.8	75.0	517	0.0100	54.2	374	0.0069	7.8	54	6.48	45	0.5	13
1WI-1435-QB	0.1610	104	11.8	52.5	73.4	506	0.0094	49.2	339	0.0061	8.1	56	6.75	47	2.8	71
2WI-1435-RA	0.1602	103	12.2	54.3	76.2	525	0.0096	47.9	330	0.0055	8.6	59	6.84	47	1.0	25
2WI-1435-RB	0.1602	103	11.4	50.7	71.2	491	0.0094	47.9	330	0.0061	7.8	54	6.78	47	1.3	33
1WI-1436-SA	0.1596	103	12.2	54.3	76.7	529	0.0100	50.6	349	0.0063	7.9	55	6.75	47	0.8	20
1WI-1436-SB	0.1587	102	13.0	57.8	81.6	563	0.0104	47.6	328	0.0055	8.8	60	6.85	47	3.5	89
			Average		77.5	534	0.0101	51.0	352	0.0063	8.1	56	6.8	47		
			Std. Dev.		3.3	23	0.0005	2.3	16	+0.0004	0.3	2	0.1	1		
			Coef. of Var. %		4.3	30	4.8	4.4	30	6.5	3.5	24	2.1	14		

TABLE C3

TENSION TEST RESULTS FOR 24-PLY 67% 0° FIBER T300/5208

UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS - TASK III

Specimen ID	Average Area, A inch^2	mm^2	Ultimate Load P_{ult} kips	KN	Ultimate Stress σ_{ult} ksi	MPa	Ultimate Strain ϵ_{ult}, in 2 inch (51 mm) in./in. (mm/mm)	Apparent Modulus E_a psi·10^6	GPa	Failure Location Distance From Tab inch	mm
2WI1477-AA	0.1206	77.8	19.6	87.2	162.1	1118	0.0112	14.5	100	2.0	51
2WI1477-BB	0.1207	77.8	19.2	85.4	159.1	1097	0.0108	14.7	101	1.8	46
2WI1441-AA	0.1197	77.2	19.2	85.4	160.4	1106	0.0109	15.1	104	0.0	0
2WI1441-BB	0.1210	78.1	18.9	84.1	155.8	1074	0.0108	14.4	99	2.6	66
1WI1443-AA	0.1205	77.7	19.1	85.0	158.1	1090	0.0110	14.4	99	2.4	61
1WI1443-BB	0.1220	78.7	18.6	82.7	152.0	1048	0.0104	14.6	101	2.0	51
Mean					157.9	1089	0.0109	14.6	101		
Standard Deviation					3.6	25	0.0003	0.3	2		
Coeff. of Var. %					2.3	2	2.5	1.8	2		

TABLE C4

TENSION TEST RESULTS FOR 32-PLY QUASI-ISOTROPIC T300/5208
UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS - TASK III

Specimen ID	Average Area, A inch²	mm²	Ultimate Load P_{ult} kip	KN	Ultimate Stress σ_{ult} ksi	MPa	Ultimate Strain ϵ_{ult}, in 2 inch (51 mm) in./in.(mm/mm)	Slope Deviation Stress σ_y, ksi	MPa	Slope Deviation Strain, ϵ_y, in 2 inch (50 mm) in./in(mm/mm)	Initial Apparent Modulus E_i psi·10⁶	gpa	Secant Modulus At Failure E_{sf} psi·10⁶	GPa	Failure Location Distance From Tab inch	mm
2WI1466-AA	0.1627	105	10.6	47.2	64.8	447	0.0082	37.3	257	0.0042	8.9	61	7.9	55	0.7	18
2WI1466-BB	0.1637	106	11.7	52.0	71.5	493	0.0099	58.6	404	0.0080	7.3	50	7.2	50	0.8	20
1WI1466-AA	0.1627	105	11.7	52.0	71.6	494	0.0090	54.4	375	0.0062	8.8	61	8.0	55	2.2	56
1WI1466-BB	0.1638	106	13.3	59.2	81.2	560	0.0110	36.6	252	0.0042	8.7	60	7.4	51	3.1	79
1WI1478-AA	0.1607	104	12.2	54.3	75.6	521	0.0110	53.4	368	0.0072	7.4	51	6.9	47	0.8	20
1WI1478-BB	0.1627	105	11.3	50.3	69.1	476	0.0090	35.3	243	0.0040	8.2	56	7.7	53	2.6	66
Mean					72.3	498	0.0097	45.9	316	0.0056	8.2	57	7.5	52		
Standard Deviation					5.6	39	0.0012	10.6	73	17.4	0.7	4.8	0.4	2.8		
Coeff. of Var. %					7.8	8	11.9	23.1	23	30.9	8.5	9	5.5	6		

TABLE C5a 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II

STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A (in.^{2})	Failure Load P_{ult}, kip	Gross Failure Stress, σ_{ult}, ksi	Apparent Failure Strain ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Initial Tangent Modulus E_i, psi x 10^6
AB-16	0.368	23.8	64.7	0.0084	7.7	8.6
BB-13	0.365	26.7	73.2	0.0095	7.7	8.9
BC-23	0.365	27.5	75.4	0.0103	7.3	8.7
CC-28	0.365	26.5	72.6	0.0096	7.6	9.3
DA-7	0.359	24.8	69.1	0.0090	7.7	8.9
DC-23	0.362	28.9	79.8	0.0109	7.3	8.9
EA-8	0.362	25.9	71.6	0.0092	7.8	8.8
EB-19	0.362	29.4	81.2	0.0111	7.3	8.9
FA-4	0.365	24.2	66.3	0.0086	7.8	9.2
FC-30	0.359	29.6	82.4	0.0108	7.6	9.1
GA-2	0.362	28.1	78.1	0.0107	7.3	8.7
GB-17	0.365	26.0	71.3	0.0095	7.5	8.8
HA-5	0.362	25.9	71.6	0.0095	7.6	8.9
IA-9	0.361	27.2	75.3	0.0099	7.6	9.2
IC-21	0.359	29.1	81.0	0.0111	7.3	9.0
		Mean	74.2	0.0099	7.5	8.9
		Std. Dev.	5.5	0.0009	0.2	0.2
		Coef. of Var. %	7.3	9.1	2.5	2.3

TABLE C5b 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II

STANDARD STRAIN RATE - 0.005 mm/mm/min.

Specimen ID	Average Gross Area, A mm^2	Failure Load, P_{ult}, kN	Gross Failure Stress σ_{ult}, MPa	Apparent Failure Strain ϵ_f, in./in. in 22.9 mm	Secant Modulus at Failure E_{sf}, GPa	Initial Tangent Modulus E_i, GPa
AB-16	237	106	446	0.0084	53	60
BB-13	235	119	505	0.0095	53	62
BC-23	235	122	520	0.0103	50	60
CC-28	235	118	501	0.0096	52	65
DA-7	232	110	476	0.0090	53	62
DC-23	234	129	550	0.0109	50	62
EA-8	234	115	494	0.0092	54	61
EB-19	234	131	560	0.0111	50	62
FA-4	235	108	457	0.0086	54	64
FC-30	232	132	568	0.0108	52	63
GA-2	234	125	538	0.0107	50	60
GB-17	235	116	492	0.0095	52	61
HA-5	234	115	494	0.0095	52	62
IA-9	233	121	519	0.0099	52	64
IC-21	232	129	558	0.0111	50	63
		Mean	512	0.0099	52	62
		Std. Div.	38	0.0009	1	1
		Coef. of Var. %	7	9.1	3	2

TABLE C6a 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II

HIGH STRAIN RATE - 5 in./in./min.

Specimen ID	Average Gross Area, A (in.^{2})	Failure Load, P_{ult}, kip	Gross Failure Stress σ_{ult}, ksi	Apparent Fracture Strain, ϵ_f, in./in. in 9 in.	Initial Tangent Modulus E_i, psi x 10^6
AB-19	0.365	22.7	62.3	0.0073	8.4
DC-25	0.362	24.7	68.1	0.0082	8.7
EA-3	0.362	25.2	69.7	0.0086	8.5
HC-28	0.362	24.9	68.8	0.0082	9.0
IB-11	0.359	24.7	68.8	0.0085	8.6
		Mean	67.5	0.0082	8.7
		Std. Dev.	3.0	0.0005	0.2
		Coef. of Var. %	4.4	6.3	2.5

TABLE C6b 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II

HIGH STRAIN RATE - 5 mm/mm/min.

Specimen ID	Average Gross Area, A (mm^2)	Failure Load P_{ult}, KN	Gross Failure Stress σ_{ult}, MPa	Apparent Fracture Strain ϵ_f, mm/mm in 228.6 mm	Initial Tangent Modulus E_i GPa
AB-19	235.5	101.0	429.5	0.0073	58
DC-25	233.5	109.9	469.5	0.0082	60
EA-3	233.5	112.1	480.6	0.0086	59
HC-28	233.5	110.8	474.4	0.0082	62
IB-11	231.6	109.9	474.4	0.0085	59
		Mean	465.4	0.0082	60
		Std. Dev.	21	0.0005	1
		Coef. of Var. %	4	6.3	3

TABLE C7a 32-PLY DAMAGED HOLE TENSION RESULTS - TASK II

STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A ($in.^2$)	Failure Load, P_{ult}, kip	Gross Failure Stress, σ_{ult}, ksi	Apparent Fracture Strain, ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Initial Tangent Modulus E_i, psi x 10^6
JA-8	0.483	21.0	43.5	0.0089	4.9	5.3
JB-17	0.486	20.0	41.2	0.0085	4.8	5.1
KC-25	0.483	20.0	41.4	0.0082	5.0	5.2
KC-26	0.484	18.5	38.2	0.0079	4.8	5.2
LB-13	0.481	19.0	39.5	0.0079	5.0	5.2
MA-3	0.483	19.3	39.9	0.0081	5.0	5.2
MC-30	0.482	20.0	41.5	0.0085	4.9	5.0
NA-7	0.484	18.3	37.7	0.0078	4.9	5.0
NA-9	0.481	19.5	40.5	0.0081	5.0	5.2
PB-11	0.483	20.5	42.4	0.0086	4.9	5.1
PC-24	0.484	19.0	39.3	0.0081	4.8	5.0
QC-26	0.486	19.8	40.7	0.0083	4.9	5.1
RB-12	0.480	20.0	41.6	0.0084	5.0	5.1
SB-12	0.480	18.5	38.5	0.0078	4.9	5.3
SC-29	0.477	19.0	39.8	0.0077	5.2	5.2
		Mean	40.4	0.0082	4.9	5.1
		Std. Dev.	1.6	0.0003	0.1	0.1
		Coef. of Var. %	4.0	4.2	2.1	2.0

TABLE C7b 32-PLY DAMAGED HOLE TENSION RESULTS - TASK II

STANDARD STRAIN RATE - 0.005 mm/mm/min.

Specimen ID	Average Gross Area, A (mm^2)	Failure Load, P_{ult}, KN	Gross Failure Stress, σ_{ult}, MPa	Apparent Fracture Strain ϵ_f, mm/mm in 228.6 mm	Secant Modulus at Failure E_{sf} GPa	Initial Tangent Modulus E_i GPa
JA-8	311.6	93.4	300	0.0089	34	37
JB-17	313.5	89.0	284	0.0085	33	35
KC-25	311.6	89.0	285	0.0082	35	36
KC-26	312.3	82.3	263	0.0079	33	36
LB-13	310.3	84.5	272	0.0079	35	36
MA-3	311.6	85.9	275	0.0081	35	36
MC-30	311.0	89.0	286	0.0085	34	35
NA-7	312.3	81.4	260	0.0078	34	35
NA-9	310.3	86.7	279	0.0081	35	36
PB-11	311.6	91.2	292	0.0086	34	35
PC-24	312.3	84.5	271	0.0081	33	35
QC-26	313.5	[illegible]	281	0.0083	34	35
RB-12	309.7	[illegible]	287	0.0084	35	35
SB-12	309.7	82.3	265	0.0078	34	37
SC-29	307.7	84.5	274	0.0077	36	36
		Mean	279	0.0082	34	35
		Std. Dev.	11	0.0003	14	1
		Coef. of Var. %	4	[illegible]	2	2

TABLE C 8a

32-PLY DAMAGED HOLE TENSION RESULTS - TASK II

HIGH STRAIN RATE - 2 in./in./min

Specimen ID	Average Gross Area, A (in.^{2})	Failure Load, P_{ult}, kip	Gross Failure Stress, σ_{ult}, ksi	Apparent Fracture Strain, ϵf, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Initial Tangent Modulus E_i, psi x 10^6
JC-29	0.485	18.4	38.1	0.0079	4.8	5.3
NC-29	0.474	19.1	40.3	0.0085	4.7	5.3
PA-8	0.483	22.3	46.2	0.0105	4.4	5.0
QB-19	0.485	18.7	38.5	0.0080	4.8	5.2
SC-21	0.472	17.4	36.8	0.0074	5.0	5.5
	Mean		40.0	0.0085	4.7	5.3
	Std. Dev.		13.4	12		0.2
	Coef. of Var. %		9.2	14.2	[illegible]	3.5

TABLE C 8b

32-PLY DAMAGED HOLE TENSION RESULTS - TASK 1I

HIGH STRAIN RATE - 2 mm/mm/min.

Specimen ID	Average Gross Area, A (mm^2)	Failure Load, P_{ult}, (KN)	Gross Failure Stress, σ_{ult}, (MPa)	Apparent Fracture Strain, ϵ_f, mm/mm in 229 mm	Secant Modulus At Failure E_{sf}, (GPa)	Initial Tangent Modulus E_i, (GPa)
JC-29	313	81	263	0.0079	33	37
NC-29	306	85	278	0.0085	32	37
PA-8	312	99	319	0.0105	30	34
QB-19	313	83	265	0.0080	33	36
SC-21	305	77	254	0.0074	34	38
	Mean		276	0.0085	32	37
	Std. Dev.		23	12	1	1
	Coef. of Var. %		9.2	14.2	5	4

TABLE C9a 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A (in.^{2})	Failure Load, P_{ult}, kip	Gross Failure Stress, σ_f, ksi	Apparent Fracture Strain, ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus at 30 ksi E_{s30} psi x 10^6
AA-4	0.365	16.1	44.1	0.0055	8.1	8.6
AA-6	0.362	16.6	45.9	0.0056	8.2	8.9
AB-18	0.365	16.4	45.0	0.0056	8.1	8.5
BB-18	0.362	17.1	47.3	0.0058	8.2	8.6
CA-8	0.365	15.7	43.0	0.0051	8.5	8.6
CC-21	0.365	15.8	43.3	0.0054	8.1	8.9
DB-11	0.359	14.8	41.2	0.0051	8.1	8.9
DB-17	0.362	17.2	47.5	0.0060	8.0	8.6
EC-22	0.362	18.1	50.0	0.0062	8.1	8.7
FB-14	0.362	16.0	44.2	0.0054	8.2	8.7
GB-19	0.362	17.1	47.3	0.0058	8.2	8.6
HB-13	0.362	14.5	40.0	0.0048	8.4	8.5
HB-18	0.361	14.6	40.4	0.0047	8.6	8.9
IA-3	0.365	15.8	43.3	0.0054	8.1	8.7
IC-29	0.365	15.9	43.9	0.0054	8.2	8.6
		Mean	44.4	0.0054	8.2	8.7
		Std. Dev.	2.8	0.0004	0.2	0.1
		Coef. of Var. %	6.3	7.6	2.0	1.7

TABLE C9b 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

STANDARD STRAIN RATE - 0.005 mm/mm/min.

Specimen ID	Average Gross Area, A mm^2	Failure Load, P_{ult}, kN	Gross Failure Stress, σ_f, MPa	Apparent Fracture Strain, ϵ_f, in./in. in 22.9 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 207 MPa E_{s207}, GPa
AA-4	235	71.6	304	0.0055	56	59
AA-6	234	73.8	316	0.0056	57	61
AB-18	235	73.0	310	0.0056	56	59
BB-18	234	76.1	326	0.0058	57	59
CA-8	235	69.8	296	0.0051	59	59
CC-21	235	70.3	299	0.0054	56	61
DB-11	232	65.8	284	0.0051	56	61
DB-17	234	76.5	328	0.0060	55	59
EC-22	234	80.5	345	0.0062	56	60
FB-14	234	71.1	305	0.0054	57	60
GB-19	234	76.1	326	0.0058	57	59
HB-13	234	64.5	276	0.0048	58	59
HB-18	233	64.9	279	0.0047	59	61
IA-3	235	70.3	299	0.0054	56	60
IC-29	235	70.7	303	0.0054	57	59
		Mean	306	0.0054	57	60
		Std. Dev.	19	0.0004	1	1
		Coef. of Var. %	6.3	7.6	2	2

TABLE C10a 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

HIGH STRAIN RATE - 5 in./in./min.

Specimen ID	Average Gross Area, A (in.^{2})	Failure Load, P_{ult}, kip	Gross Failure Stress, σ_{ult}, ksi	Apparent Fracture Strain, ϵ_f, in./in. in 9 in.	Initial Tangent Modulus E_i, psi x 10^6
EC-23	0.362	13.0	36.0	0.0045	8.6
FB-13	0.362	13.3	36.8	0.0046	9.2
FC-21	0.359	13.4	37.5	0.0047	8.6
GB-14	0.362	12.0	33.1	0.0044	8.2
GC-30	0.365	15.0	41.1	0.0052	8.7
		Mean	36.9	0.0047	8.7
		Std. Dev.	2.9	0.0003	0.4
		Coef. of Var. %	7.8	6.7	4.1

TABLE C10b 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

HIGH STRAIN RATE - 5 mm/mm/min.

Specimen ID	Average Gross Area, A (mm^2)	Failure Load P_{ult}, KN	Gross Failure Stress σ_{ult}, MPa	Apparent Fracture Strain ϵ_f, mm/mm in 228.6 mm	Initial Tangent Modulus E_i GPa
EC-23	233.5	57.8	248	0.0045	59
FB-13	233.5	59.2	254	0.0046	64
FC-21	231.6	59.6	259	0.0047	59
GB-14	233.5	53.4	226	0.0044	57
GC-30	235.5	66.7	283	0.0052	60
		Mean	254	0.0047	60
		Std. Dev.	20	0.0003	3
		Coef. of Var. %	8	7	4

TABLE C11a 32-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A ($in.^2$)	Failure Load, P_{ult}, kip	Gross Failure Stress, σ_{ult}, ksi	Apparent Fracture Strain, ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Initial Tangent Modulus E_i, psi x 10^6
JC-21	0.481	16.5	34.3	0.0073	4.7	5.2
JC-26	0.487	17.5	36.0	0.0077	4.7	5.0
KB-13	0.485	16.8	34.6	0.0075	4.6	5.1
LA-8	0.482	17.5	36.3	0.0076	4.8	5.2
LC-29	0.483	17.0	35.2	0.0074	4.7	5.1
MA-7	0.483	15.8	32.6	0.0069	4.7	5.1
MC-24	0.482	16.0	33.2	0.0070	4.8	5.2
NB-11	0.481	17.5	36.3	0.0077	4.7	5.3
PC-18	0.483	16.3	33.6	0.0070	4.8	5.2
QA-5	0.486	15.6	32.2	0.0068	4.8	5.2
QB-16	0.488	17.0	34.8	0.0073	4.8	5.1
RA-4	0.483	15.4	31.9	0.0066	4.9	5.0
RB-18	0.480					
RC-30	0.489	17.0	35.4	0.0074	4.8	5.3
S-15	0.483	15.5	32.1	0.0066	4.8	5.0
		Mean	34.2	0.0072	4.8	5.1
		Std. Dev.	1.5	0.0004	0.1	0.1
		Coef. of Var. %	4.5	5.3	1.6	2.0

TABLE C11b 32-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

STANDARD STRAIN RATE - 0.005 mm/mm/min.

Specimen ID	Average Gross Area, A (mm^2)	Failure Load, P_{ult}, KN	Gross Failure Stress, σ_{ult}, MPa	Apparent Fracture Strain ϵ_f, mm/mm in 228.6 mm	Secant Modulus at Failure E_{sf} GPa	Initial Tangent Modulus E_i GPa
JC-21	310.3	73.4	237	0.0073	32	36
JC-26	314.2	77.8	248	0.0077	32	35
KB-13	312.9	74.7	239	0.0075	32	35
LA-8	311.0	77.8	250	0.0076	33	36
LC-29	311.6	75.6	243	0.0074	32	35
MA-7	311.6	70.3	225	0.0069	32	35
MC-24	311.0	71.2	230	0.0070	33	36
NB-11	310.3	77.8	250	0.0077	32	37
PC-18	311.6	72.5	232	0.0070	33	36
QA-5	313.5	69.4	222	0.0068	33	36
QB-16	314.8	75.6	240	0.0073	33	35
RA-4	311.6	68.5	220	0.0066	34	35
RB-18	309.7					
RC-30	315.5	75.6	244	0.0074	33	37
S-15	311.6	68.9	221	0.0066	33	35
		Mean	236	0.0072	33	35
		Std. Dev.	10	0.0004	1	1
		Coef. of Var. %	5	5	2	2

TABLE C12a

32-PLY DAMAGED HOLE COMPRESSION RESULTS - TASK II

(WITH FATIGUE SUPPORT)

HIGH STRAIN RATE - 0.5 in./in./min.

Specimen ID	Average Gross Area, A (in.^{2})	Failure Load, P_{ult}, kip	Gross Failure Stress, σ_{ult}, ksi	Apparent Fracture Strain, ϵ_f, in./in. in 9 in.	Secant Modulus At Failure E_{sf}, psi x 10^6	Initial Tangent Modulus E_i, psi x 10^6
KA-6	0.486	16.3	33.5	0.0072	4.7	5.3
KA-8	0.486	13.9	28.6	0.0057	5.0	5.0
NB-15	0.486	11.1	22.9	0.0046	5.0	5.0
RA-3	0.482	13.3	27.6	0.0066	4.2	4.8
RC-26	0.483	16.3	33.8	0.0073	4.6	5.2
Mean			29.3	0.0063	4.7	5.1
Std. Dev.			4.5	0.0010	0.3	0.2
Coef. of Var. %			15.5	18.1	7.1	3.9

TABLE C12b

32-PLY DAMAGED HOLE COMPRESSION RESULTS - TASK II

(WITH FATIGUE SUPPORT)

HIGH STRAIN RATE - 0.5 mm/mm/min.

Specimen ID	Average Gross Area, A (mm^2)	Failure Load, P_{ult}, (KN)	Gross Failure Stress, σ_{ult}, (MPa)	Apparent Fracture Strain, ϵ_f, mm/mm in 229 mm	Secant Modulus At Failure E_{sf}, (GPa)	Initial Tangent Modulus E_i, (GPa)
KA-6	314	73	231	0.0072	32	37
KA-8	314	62	197	0.0057	34	34
NB-15	314	49	158	0.0046	34	34
RA-3	311	59	190	0.0066	29	33
RC-26	312	73	233	0.0073	32	36
	Mean		202	0.0063	32	35
	Std. Dev.		31	0.0011	2	1
	Coef. of Var. %		16	18.1	7	4

TABLE C13a

STATIC TENSION TEST
RESULTS - TASK III

Specimen ID	Average Gross Area, A $in.^2$	Failure Load P_{ult}, kips	Gross Failure Stress σ_{ult}, ksi	Apparent Strain at Failure ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_f, psi x 10^6	Initial Tangent Modulus E_i, psi x 10^6
24 PLY LAMINATE						
AB-18	0.3628	24.6	67.8	0.0092	7.4	8.8
BA-2	0.3652	25.8	70.9	0.0099	7.2	8.7
CC-22	0.3577	26.4	73.8	0.0103	7.2	8.9
Mean			70.8	0.0098	7.2	8.8
Std. Dev.			3.0	0.0006	0.1	0.1
Coeff. of Var. %			4.2	5.7	1.6	1.3
32 PLY LAMINATE						
DC-24	0.4871	18.4	37.8	0.0090	4.2	5.0
EC-26	0.4862	20.2	41.5	0.0092	4.5	5.3
FB-12	0.4791	19.5	40.7	0.0083	4.9	5.0
Mean			40.0	0.0088	4.5	5.1
Std. Dev.			1.9	0.0005	0.4	0.2
Coeff. of Var. %			4.9	5.3	7.7	3.7

TABLE C13b

STATIC TENSION TEST
RESULTS - TASK III

Specimen ID	Average Gross Area, A mm^2	Failure Load P_{ult}, KN	Gross Failure Stress σ_{ult}, MPa	Apparent Failure Strain ϵ_f, mm/mm	Secant Modulus at Failure E_{sf}, GPa	Initial Tangent Modulus E_i, GPa
24 PLY LAMINATE						
AB-18	234	109.4	467	0.0092	51	61
BA-2	236	114.8	489	0.0099	49	60
CC-22	231	117.4	509	0.0103	49	62
Mean			488	0.0098	50	62
Std. Dev.			20.7	0.0006	0.8	0.8
Coeff. of Var. %			4.2	5.7	1.6	1.3
32 PLY LAMINATE						
DC-24	314	81.8	261	0.0090	29.	34
EC-26	314	89.9	286	0.0092	31.	37
FB-12	309	86.7	281	0.0083	34	34
Mean			275	0.0088	31	35
Std. Dev.			13.1	0.0005	2	1
Coeff. of Var. %			4.9	5.3	8	4

TAPLE C14a

STATIC COMPRESSION TEST
RESULTS WITH FATIGUE SUPPORT - TASK III

Specimen ID	Average Gross Area, A in.^{2}	Failure Load P_{ult}, kips	Gross Failure Stress σ_{ult}, ksi	Apparent Strain at Failure ϵ_f in./in. in 9 in.	Secant Modulus at Failure E_f psi x 10^6	Secant Modulus $E_s{}^a$ psi x 10^6
24 PLY LAMINATE						
AC-28	0.3672	17.8	48.3	0.0077	6.3	8.0
BC-30	0.3601	14.5	40.3	0.0056	7.2	8.3
CC-25	0.3645	18.5	50.8	0.0086	5.6	8.0
Mean			46.5	0.0073	6.4	8.1
Std. Dev.			5.5	0.0015	0.8	0.2
Coeff. of Var. %			11.8	21.1	12.6	2.2
32 PLY LAMINATE						
DA-2	0.4898	17.5	35.7	0.0094	3.8	4:6
EB-14	0.4884	17.2	35.3	0.0090	3.9	4.6
FB-17	0.4856	17.5	36.0	0.0096	3.8	4.7
Mean			35.7	0.0093	3.8	4.6
Std. Dev.			0.4	0.0003	0.1	0.1
Coeff. of Var. %			1.0	3.3	2.3	1.3

a = Secant Modulus E_{s30} at 30 ksi for 24-ply laminate and E_{s20} at 20 ksi for 32-ply laminate

TABLE C14b

STATIC COMPRESSION TEST
RESULTS WITH FATIGUE SUPPORT - TASK III

Specimen ID	Average Gross Area, A mm^2	Failure Load P_{ult}, KN	Gross Failure Stress σ_{ult}, MPa	Apparent Failure Strain ϵ_f mm/mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus E_s [a] GPa
24 PLY LAMINATE						
AC-28	237	79.2	333	0.0077	43	55
BC-30	232	64.5	278	0.0056	50	57
CC-25	235	82.3	350	0.0086	39	55
Mean			321	0.0073	44	56
Std. Dev.			37.9	0.0015	6	1
Coeff. of Var. %			11.8	21.1	13	2
32 PLY LAMINATE						
DA-2	316	77.8	246	0.0094	26	31
EB-14	315	77.0	243	0.0090	27	31
FB-17	313	77.8	248	0.0096	26	32
Mean			246	0.0093	26	32
Std. Dev.			2.8	0.0003	1	1
Coeff. of Var. %			1.0	3.3	2	1

a = Secant modulus E_{s30} at 30 ksi for 24-ply laminate and E_{s20} at 20 ksi for 32-ply laminate

TABLE C15a

STATIC COMPRESSION TEST

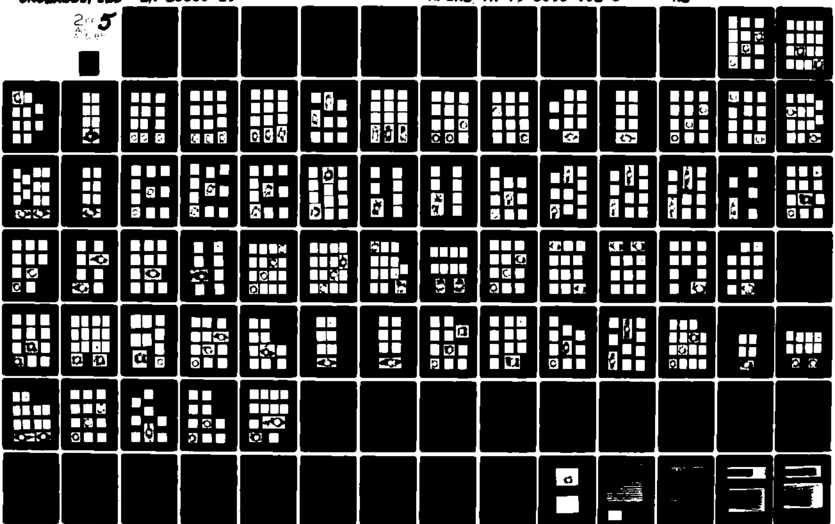
RESULTS WITH 4-BAR COLUMN BUCKLING SUPPORT - TASK III

Specimen ID	Average Gross Area, A in.^{2}	Failure Load P_{ult}, kips	Failure Stress σ_{ult}, ksi	Apparent Strain at Failure ϵ_f in./in. in 9 in.	Secant Modulus at Failure E_f psi x 10^6	Secant Modulus E_s[a] psi x 10^6
24 PLY LAMINATE						
AB-17	0.3672	14.5	39.5	0.0051	7.8	8.9
BC-26	0.3648	16.5	45.2	0.0061	7.4	8.8
CB-17	0.3648	15.0	41.1	0.0056	7.3	8.7
Mean			41.9	0.0056	7.5	8.8
Std. Dev.			2.9	0.0005	0.2	0.1
Coeff. of Var. %			7.0	8.9	2.9	1.1
32 PLY LAMINATE						
DA-4	0.4898	15.0	30.6	0.0065	4.7	4.9
EA-2	0.4868	20.0	41.1	0.0091	4.5	5.00
FB-16	0.4870	16.3	33.4	0.0071	4.7	4.9
Mean			35.0	0.0076	4.6	4.9
Std. Dev.			5.4	0.0014	0.1	0.1
Coeff. of Var. %			15.5	18.0	2.3	1.4

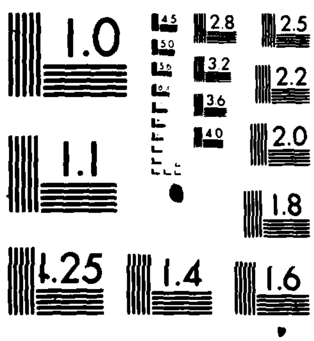
a = Secant modulus E_{s30} at 30 ksi for 24-ply laminate and E_{s20} at 20 ksi for 32-ply laminate.

AD-A115 185 LOCKHEED-CALIFORNIA CO BURBANK F/G 11/4
ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC--ETC(U)
JUL 81 K N LAURAITIS, J T RYDER, D E PETTIT F33615-77-C-3084
UNCLASSIFIED LR-28360-19 AFWAL-TR-79-3095-VOL-3 NL

2 OF 5



115/85



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

TABLE C15b

STATIC COMPRESSION TEST
RESULTS WITH 4-BAR COLUMN BUCKLING SUPPORT - TASK III

Specimen ID	Average Gross Area, A mm^2	Failure Load P_{ult}, KN	Gross Failure Stress P_{ult}, MPa	Apparent Failure Strain ϵ_f mm/mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus E_s[a] GPa
24 PLY LAMINATE						
AB-17	237	64.5	272	0.0051	53	61
BC-26	235	73.4	312	0.0061	51	61
CB-17	235	66.7	283	0.0056	51	60
Mean			289	0.0056	52	61
Std. Dev.			20	0.0005	2	1
Coeff. of Var. %			7	8.9	3	1
32 PLY LAMINATE						
DA-4	316	66.7	211	0.0065	33	34
EA-2	314	89.0	283	0.0091	31.2	35
FB-16	314	72.7	230	0.0071	32.4	34
Mean			241	0.0076	32	34
Std. Dev.			37	0.0014	1	1
Coeff. of Var. %			16	18.0	2	1

a = Secant modulus E_s30 at 30 ksi for 24-ply laminate and E_s20 at 20 ksi for 32-ply laminate.

TABLE C16a

24-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A in.^{2}	Failure Load P_{ult}, kip	Gross Failure Stress σ_{ult}, ksi	Apparent Failure Strain ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi X 10^6	Initial Tangent Modulus E_i, psi X 10^6
4000	AB-13	0.365	28.0	76.7	0.0100	7.7	8.6
	BA-9	0.362	29.9	82.7	0.0106	7.8	8.9
	CC-23	0.362	28.6	78.7	0.0107	7.3	8.7
	EA-7	0.362	27.5	76.0	0.0097	7.8	8.8
	EC-27	0.365	29.5	80.8	0.0095	8.5	9.4
	FC-25	0.365	28.2	77.4	0.0101	7.7	9.2
	GB-16	0.363	30.1	83.0	0.0115	7.2	8.9
	HC-24	0.365	29.9	81.9	0.0115	7.1	8.6
	IA-1	0.360	27.2	75.5	0.0100	7.6	9.1
8000	AA-7	0.363	28.5	78.4	0.0098	8.0	9.0
	BC-30	0.362	31.8	87.7	0.0117	7.5	8.8
	CB-16	0.360	29.5	82.0	0.0111	7.4	8.8
	DC-29	0.362	31.5	86.9	0.0113	7.7	8.8
	EC-24	0.366	29.2	79.6	0.0100	8.0	9.4
	FB-11	0.368	29.2	79.4	0.0108	7.3	8.7
	FC-26	0.363	26.2	72.3	0.0092	7.9	8.8
	GC-22	0.362	29.3	81.0	0.0106	7.7	9.0
	IB-15	0.360	29.5	81.9	0.0112	7.3	8.8
12000	AA-5	0.368	30.0	81.5	0.0114	7.2	8.6
	AC-27	0.366	29.5	80.6	0.0111	7.8	8.6
	BC-21	0.365	31.0	85.0	0.0116	7.3	8.7
	CB-14	0.363	30.0	82.6	0.0112	7.4	9.0
	DA-10	0.342	31.5	92.2	0.0126	7.3	9.1
	DB-15	0.365	31.3	85.6	0.0129	6.6	8.3
	GB-18	0.360	29.8	82.6	0.0106	7.8	8.9
	IA-2	0.362	29.0	80.0	0.0108	7.4	8.9
20000	AC-25	0.367	30.7	83.7	0.0113	7.4	8.6
	CB-17	0.365	32.6	89.4	0.0122	7.3	9.0
	FB-15	0.365	30.3	83.0	0.0111	7.5	8.6
	GC-24	0.360	30.0	83.3	0.0112	7.5	8.7
	GC-25	0.362	28.8	79.4	0.0107	7.4	8.9
40000	BC-25	0.364	32.4	89.1	0.0118	7.6	8.7
	CB-19	0.364	31.5	86.5	0.0107	8.1	9.1
	FC-27	0.366	32.4	88.4	0.0111	8.0	9.1
	GA-9	0.359	31.9	88.8	0.0116	7.7	9.6
	HC-30	0.362	30.1	83.3	0.0107	7.8	8.9

TABLE C16b

24-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm^2	Failure Load P_{ult}, KN	Gross Failure Stress σ_{ult}, MPa	Apparent Failure Strain ϵ_f, mm/mm in 229 mm	Secant Modulus at Failure E_{sf}, GPa	Initial Tangent Modulus E_i, GPa
4000	AB-13	235	125	529	0.0100	53	59
	BA-9	234	133	570	0.0106	54	61
	CC-23	234	127	543	0.0107	50	60
	EA-7	234	122	524	0.0097	54	61
	EC-27	235	131	557	0.0095	59	65
	FC-25	235	125	534	0.0101	53	63
	GB-16	234	134	572	0.0115	50	61
	HC-24	235	133	565	0.0115	49	59
	IA-1	232	121	521	0.0100	52	63
8000	AA-7	234	127	541	0.0098	55	62
	BC-30	234	141	605	0.0117	52	61
	CB-16	232	131	565	0.0111	51	61
	DC-29	234	140	599	0.0113	53	61
	EC-24	236	130	549	0.0100	55	65
	FB-11	237	130	547	0.0108	50	60
	FC-26	234	117	498	0.0092	54	61
	GC-22	234	130	558	0.0106	53	62
	IB-15	232	131	565	0.0112	50	61
12000	AA-5	237	133	562	0.0114	50	59
	AC-27	236	131	556	0.0111	54	59
	BC-21	235	138	586	0.0116	50	60
	CB-14	234	133	570	0.0112	51	62
	DA-10	221	140	636	0.0126	50	63
	DB-15	235	139	590	0.0129	46	57
	GB-18	232	133	570	0.0106	54	61
	IA-2	234	129	552	0.0108	51	61
20000	AC-25	237	137	577	0.0113	51	59
	CB-17	235	145	616	0.0122	50	62
	FB-15	235	135	572	0.0111	52	59
	GC-24	232	133	574	0.0112	52	60
	GC-25	234	128	547	0.0107	51	61
40000	BC-25	235	144	614	0.0118	52	60
	CB-19	235	140	596	0.0107	56	63
	FC-27	236	144	609	0.0111	55	63
	GA-9	232	142	612	0.0116	53	66
	HC-30	234	134	574	0.0107	54	61

TABLE C17a

24-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II
(With Fatigue Supports)

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A in.^{2}	Failure Load P_{ult}, kip	Gross Failure Stress σ_f, ksi	Apparent Fracture Strain ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi X 10^6	Secant Modulus at 30 ksi E_{s30} psi X 10^6
4000	AB-14	0.368	17.5	47.6	0.0064	7.5	8.3
	AC-29	0.366	16.5	45.1	0.0057	7.9	8.5
	BA-1	0.357	16.0	44.8	0.0057	7.9	8.6
	DC-22	0.362	18.0	50.0	0.0064	7.8	8.6
	EC-25	0.362	15.5	42.9	0.0055	7.8	8.5
	FB-19	0.364	17.3	47.4	0.0062	7.7	8.6
	FC-24	0.363	15.8	43.4	0.0054	8.0	8.4
	GA-4	0.362	16.8	46.3	0.0060	7.8	8.3
	HA-2	0.363	14.0	38.5	0.0050	7.7	8.3
	HA-7	0.361	19.5	54.0	0.0072	7.5	8.6
8000	AC-24	0.365	16.6	45.4	0.0057	8.0	8.4
	CB-12	0.361	17.3	47.9	0.0060	8.0	8.9
	DA-5	0.362	15.4	42.2	0.0053	8.0	8.5
	DB-18	0.361	17.5	48.5	0.0059	8.2	8.9
	EA-5	0.362	14.6	40.3	0.0051	7.8	8.3
	EC-29	0.363	17.6	48.5	0.0061	7.9	8.9
	GA-6	0.363	17.1	47.1	0.0061	7.7	8.2
	HB-16	0.365	15.7	42.9	0.0056	7.7	8.3
	IC-27	0.364	16.4	45.0	0.0059	7.6	8.2
12000	BB-19	0.363	17.8	49.0	0.0065	7.5	8.2
	CA-2	0.359	19.5	54.3	0.0068	8.0	8.9
	FA-1	0.359	16.3	45.2	0.0058	7.8	8.6
	GA-5	0.361	17.5	48.4	0.0065	7.5	8.3
	HA-6	0.363	19.3	53.0	0.0072	7.4	8.4
	HC-21	0.357	16.0	44.8	0.0059	7.6	8.3
	IA-6	0.364	18.3	50.1	0.0066	7.6	8.6
20000	AA-3	0.365	16.8	46.2	0.0058	8.0	8.6
	BB-14	0.366	16.3	44.7	0.0056	7.9	8.6
	DB-14	0.366	16.4	44.9	0.0058	7.7	8.3
	FA-2	0.364	14.4	39.4	0.0050	7.9	8.4
	FC-29	0.363	18.6	51.3	0.0061	8.4	8.8
40000	AC-26	0.370	17.3	46.6	0.0058	8.0	8.6
	CC-24	0.363	19.8	54.5	0.0068	8.0	8.9
	CC-27	0.363	17.7	48.7	0.0063	7.8	8.8
	EA-9	0.364	14.9	40.9	0.0049	8.4	8.8
	IB-16	0.363	17.5	48.2	0.0061	7.9	8.7

TABLE C17b

24-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II
(With Fatigue Supports)

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm^2	Failure Load P_{ult}, KN	Gross Failure Stress σ_f, MPa	Apparent Fracture Strain ϵ_f, mm/mm in 229 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 30 ksi E_{s30} GPa
4000	AB-14	237	77.8	328	0.0064	52	57
	AC-29	236	73.4	311	0.0057	54	59
	BA-1	230	71.2	309	0.0057	54	59
	DC-22	234	80.1	345	0.0064	54	59
	EC-25	234	68.9	296	0.0055	54	59
	FB-19	235	77.0	327	0.0062	53	59
	FC-24	234	70.3	299	0.0054	55	58
	GA-4	234	74.7	319	0.0060	54	57
	HA-2	234	62.3	265	0.0050	53	57
	HA-7	233	86.7	372	0.0072	52	59
8000	AC-24	235	73.8	313	0.0057	55	58
	CB-12	233	77.0	330	0.0060	55	61
	DA-5	234	68.5	291	0.0053	55	59
	DB-18	233	77.8	334	0.0059	57	61
	EA-5	234	64.9	278	0.0051	54	57
	EC-29	234	78.3	334	0.0061	54	61
	GA-6	234	76.1	325	0.0061	53	57
	HB-16	235	69.8	296	0.0056	53	57
	IC-27	235	73.0	310	0.0059	52	57
1[illegible]000	BB-19	234	79.2	338	0.0065	52	57
	CA-2	232	86.7	374	0.0068	55	61
	FA-1	232	72.5	312	0.0058	54	59
	GA-5	233	77.8	334	0.0065	52	57
	HA-6	234	85.9	365	0.0072	51	58
	HC-21	230	71.2	309	0.0059	52	57
	IA-6	235	81.4	345	0.0066	52	59
20000	AA-3	235	74.7	319	0.0058	55	59
	BB-14	236	72.5	308	0.0056	54	59
	DB-14	236	73.0	310	0.0058	53	57
	FA-2	235	64.1	272	0.0050	54	58
	FC-29	234	82.7	354	0.0061	58	61
40000	AC-26	239	77.0	321	0.0058	55	59
	CC-24	234	88.1	376	0.0068	55	61
	CC-27	234	78.7	336	0.0063	54	61
	EA-9	235	66.3	282	0.0049	58	61
	IB-16	234	77.8	332	0.0061	54	60

TABLE C18a

32-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A in.^{2}	Failure Load P_{ult}, kip	Gross Failure Stress σ_{ult}, ksi	Apparent Failure Strain ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf} psi x 10^6	Initial Tangent Modulus E_i, psi x 10^6
1,000	JB-16	0.4853	20.6	42.4	0.0097	4.37	4.74
	JC-22	0.4832	20.7	42.8	0.0098	4.37	4.76
	KA-9	0.4856	21.9	45.0	0.0104	4.33	4.90
	KB-18	0.4825	20.0	41.4	0.0091	4.55	5.02
	LA-3	0.4859	21.1	43.3	0.0100	4.33	4.90
	NC-28	0.4830	21.1	43.6	0.0102	4.27	4.89
	NC-30	0.4840	20.1	41.4	0.0092	4.50	4.88
	PA-9	0.4850	20.7	42.7	0.0096	4.45	4.80
	QB-17	0.4870	20.8	42.7	0.0096	4.45	4.76
	RA-2	0.4832	21.1	43.7	0.0094	4.65	5.05
5,000	JA-4	0.4820	20.5	42.5	0.0090	4.72	4.94
	KB-16	0.4812	21.0	43.6	0.0100	4.36	4.86
	KC-28	0.4817	21.4	44.4	0.0090	4.93	5.32
	LA-2	0.4847	20.8	42.8	0.0095	4.51	4.83
	MB-16	0.4842	23.5	48.5	0.0103	4.71	5.74
	NC-22	0.4825	22.8	47.2	0.0100	4.72	5.18
	NC-26	0.4860	22.4	46.0	0.0094	4.89	5.42
	QA-1	0.4877	20.8	42.5	0.0090	4.72	5.13
	QA-9	0.4845	19.8	40.8	0.0088	4.64	4.91
	SB-13	0.4816	20.2	42.0	0.0088	4.77	5.02
10,000	KA-7	0.4860	21.4	43.9	0.0094	4.67	4.98
	LA-7	0.4831	20.8	43.0	0.0088	4.89	5.18
	LC-27	0.4822	20.0	41.6	0.0086	4.84	5.18
	MC-29	0.4679	22.0	47.0	0.0094	5.00	5.23
	NB-16	0.4869	21.3	43.7	0.0091	4.80	5.13
	PA-1	0.4778	22.2	46.6	0.0095	4.91	4.98
	PA-4	0.4786	20.7	43.3	0.0089	4.87	4.97
	QB-12	0.4860	23.3	47.9	0.0099	4.84	5.14
	RB-17	0.4820	20.6	42.8	0.0087	4.92	5.05
	SA-5	0.4799	21.1	44.0	0.0088	5.00	5.37
20,000	JB-15	0.4838	21.5	44.4	0.0094	4.72	5.17
	KB-12	0.4868	20.3	41.7	0.0087	4.79	5.34
	LA-4	0.4824	21.6	44.9	0.0093	4.83	5.18
	LA-5	0.4857	22.0	45.3	0.0091	4.98	5.15
	MB-13	0.4839	20.9	43.2	0.0092	4.70	5.03
	MB-18	0.4833	21.3	44.1	0.0089	4.96	5.17
	NB-17	0.4856	21.2	43.8	0.0092	4.76	4.90
	QC-30	0.4843	21.2	43.7	0.0091	4.80	5.03
	RC-24	0.4832	20.9	43.2	0.0092	4.70	4.93
	SC-23	0.4783	20.7	43.3	0.0089	4.87	5.09
28,000	JC-23	0.4825	21.9	45.4	0.0098	4.63	4.94
	KA-5	0.4852	22.2	45.8	0.0099	4.63	4.91
	KB-14	0.4838	21.8	45.2	0.0098	4.61	4.92
	MA-4	0.4814	20.4	42.2	0.0096	4.39	4.71
	NB-14	0.4857	21.9	45.1	0.0094	4.80	5.42
	PB-12	0.4816	21.8	45.3	0.0098	4.62	4.86
	PB-13	0.4839	20.2	41.7	0.0089	4.69	4.92
	QC-31	0.4787	23.3	48.7	0.0101	4.82	5.44
	RA-5	0.4826	21.0	43.4	0.0089	4.88	5.18
	SB-18	0.4806	21.8	45.4	0.0097	4.68	4.95

TABLE C18b

32-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm^2	Failure Load P_{ult}, KN	Gross Failure Stress σ_{ult}, MPa	Apparent Failure Strain ϵ_f, mm/mm in 228.6 mm	Secant Modulus at Failure E_{sf}, GPa	Initial Tangent Modulus E_i, GPa
1,000	JB-15	313	91.6	292	0.0097	30.1	32.7
	JC-22	312	92.1	295	0.0098	30.1	32.8
	KA-9	313	97.2	310	0.0104	29.8	33.8
	KB-18	311	89.0	285	0.0091	31.4	34.6
	LA-3	314	93.9	298	0.0100	29.8	33.8
	NC-28	312	93.9	301	0.0102	29.4	33.7
	NC-30	312	89.4	285	0.0092	31.0	33.7
	PA-9	313	92.1	294	0.0096	30.7	33.1
	QB-17	314	92.5	294	0.0096	30.7	32.8
	RA-2	312	93.9	301	0.0094	32.1	34.8
5,000	JA-4	311	91.2	293	0.0090	32.5	34.1
	KB-16	310	93.4	301	0.0100	30.1	33.5
	KC-28	311	95.2	306	0.0090	34.0	36.7
	LA-2	313	92.5	295	0.0095	31.1	33.3
	MB-16	312	104.5	334	0.0103	32.5	39.6
	NC-22	311	101.4	325	0.0100	32.5	35.7
	NC-26	314	99.6	317	0.0094	33.7	37.4
	QA-1	315	92.5	293	0.0090	32.5	35.4
	QA-9	313	88.1	281	0.0088	32.0	33.8
	SB-13	311	89.8	290	0.0088	32.9	34.6
10,000	KA-7	314	95.2	303	0.0094	32.2	34.3
	LA-7	312	92.5	296	0.0088	33.7	35.7
	LC-27	311	89.0	287	0.0086	33.4	35.7
	MC-29	302	97.9	324	0.0094	34.5	36.1
	NB-16	314	94.8	301	0.0091	33.1	35.4
	PA-1	308	98.8	321	0.0095	33.8	34.3
	PA-4	309	92.1	298	0.0089	33.6	34.3
	QB-12	314	103.6	330	0.0099	33.4	35.4
	RB-17	311	91.6	295	0.0087	33.9	34.8
	SA-5	310	93.9	303	0.0088	34.5	37.0
20,000	JB-15	312	95.6	306	0.0094	32.5	35.6
	KB-12	314	90.3	288	0.0087	33.0	36.8
	LA-4	311	96.1	310	0.0093	33.3	35.7
	LA-5	313	97.9	312	0.0091	34.3	35.5
	MB-13	312	93.0	298	0.0092	32.4	34.7
	MB-18	312	94.8	304	0.0089	34.2	35.6
	NB-17	313	94.3	302	0.0092	32.8	33.8
	QC-30	312	94.3	301	0.0091	33.1	34.7
	RC-24	312	93.0	298	0.0092	32.4	34.0
	SC-23	309	92.1	298	0.0089	33.6	35.1
28,000	JC-23	311	97.4	313	0.0098	31.9	34.1
	KA-5	313	98.8	316	0.0099	31.9	33.8
	KB-14	312	97.0	312	0.0098	31.8	33.9
	MA-4	311	90.7	291	0.0096	30.3	32.5
	NB-14	313	97.4	311	0.0094	33.1	37.4
	PB-12	311	97.0	312	0.0098	31.8	33.5
	PB-13	312	89.8	288	0.0089	32.3	33.9
	QC-31	309	103.6	336	0.0101	33.2	37.5
	RA-5	311	93.4	299	0.0089	33.6	35.7
	SB-18	310	97.0	313	0.0097	32.3	34.1

TABLE C19a

32-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A in.^{2}	Failure Load P_{ult}, kip	Gross Failure Stress ult, ksi	Apparent Failure Strain ϵ_f, in./in. in 9 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus at 20 ksi E_{s20}, psi x 10^6
1,000	JB-13	0.4854	17.1	35.2	0.0090	3.91	4.65
	KC-27	0.4868	16.7	34.2	0.0081	4.22	4.76
	MA-8	0.4860	15.2	31.3	0.0069	4.54	4.88
	MC-28	0.4831	15.8	32.7	0.0083	3.94	5.00
	NA-4	0.4832	15.2	31.5	0.0070	4.50	4.76
	PA-3	0.4831	17.3	35.8	0.0092	3.89	4.65
	QA-6	0.4841	15.0	31.0	0.0069	4.49	4.88
	SA-7	0.4781	14.5	30.3	0.0068	4.46	4.76
	SB-19	0.4826	16.0	33.2	0.0074	4.49	4.88
5,000	JA-5	0.4858	14.3	29.3	0.0066	4.44	4.65
	KC-24	0.4841	16.0	33.1	0.0074	4.47	4.88
	LB-16	0.4872	16.3	33.4	0.0074	4.51	4.88
	MA-6	0.4854	15.5	31.9	0.0071	4.49	4.88
	NA-2	0.4834	15.3	31.5	0.0070	4.50	4.76
	PB-15	0.4833	18.0	37.2	0.0088	4.23	4.76
	PC-25	0.4823	15.8	32.7	0.0076	4.30	4.65
	QC-28	0.4838	15.5	32.0	0.0072	4.44	4.65
	RB-20	0.4721	17.5	37.1	0.0082	4.52	4.88
	RC-27	0.4797	16.0	33.4	0.0073	4.58	5.00
10,000	JC-27 [a]	0.4855	-	-	-	-	-
	JC-28	0.4849	14.3	29.5	0.0068	4.32	4.58
	KC-22	0.4817	14.9	30.8	0.0068	4.56	4.87
	LC-23	0.4821	13.7	28.3	0.0063	4.49	4.65
	MC-25	0.4847	16.6	34.2	0.0080	4.26	4.80
	NB-13	0.4842	17.7	36.6	0.0084	4.36	4.80
	PC-27	0.4831	16.0	33.1	0.0076	4.37	4.65
	QC-23	0.4844	16.5	34.0	0.0076	4.50	4.87
	SA-3	0.4817	15.5	32.1	0.0071	4.55	4.87
	SB-11	0.4730	14.5	30.7	0.0069	4.42	4.90
20,000	JB-11	0.4805	14.1	29.3	0.0063	4.65	5.00
	LC-31	0.4714	15.9	33.7	0.0074	4.55	4.88
	MB-11	0.4750	17.2	36.1	0.0072	5.01	5.26
	NA-6	0.4849	14.9	30.6	0.0067	4.57	4.88
	PB-17	0.4840	16.4	33.9	0.0070	4.64	4.88
	QB-13	0.4862	14.7	30.2	0.0068	4.44	4.88
	QC-22	0.4844	13.8	28.5	0.0063	4.52	4.88
	RA-7	0.4829	13.6	28.2	0.0064	4.41	4.88
	RC-22	0.4841	14.0	28.8	0.0062	4.65	4.88
	SC-27	0.4772	15.5	32.4	0.0070	4.63	5.00
28,000	JB-18	0.4836	14.3	29.5	0.0066	4.47	4.65
	KB-17	0.4828	15.5	32.1	0.0076	4.22	4.65
	LB-19	0.4815	16.7	34.7	0.0075	4.63	4.93
	LC-26	0.4841	16.9	34.9	0.0083	4.20	4.67
	MB-15	0.4828	18.7	38.7	0.0096	4.05	4.83
	NB-18	0.4854	15.0	30.9	0.0068	4.54	4.88
	PA-7	0.4839	16.0	33.1	0.0076	4.36	4.65
	RC-25	0.4826	15.0	31.2	0.0070	4.46	4.76
	RC-31	0.4756	17.0	35.7	0.0078	4.58	4.88
	SB-17	0.4794	13.5	28.2	0.0064	4.40	4.76

a = Failed on loading due to operator error

TABLE C19b

32-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm^2	Failure Load P_{ult}, KN	Gross Failure Stress σ_{ult}, MPa	Apparent Failure Strain ϵ_f, mm/mm in 228.6 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 138 MPa E_{s138} GPa
1,000	JB-13	313	76.0	243	0.0090	27.0	32.1
	KC-27	314	74.3	236	0.0081	29.1	32.8
	MA-8	314	67.6	216	0.0069	31.3	33.6
	MC-28	312	70.3	225	0.0083	27.2	34.5
	NA-4	312	67.6	217	0.0070	31.0	32.8
	PA-3	312	77.0	247	0.0092	26.8	32.1
	QA-6	312	66.7	214	0.0069	31.0	33.6
	SA-7	308	64.5	209	0.0068	30.8	32.8
	SB-19	311	71.2	229	0.0074	31.0	33.6
5,000	JA-5	313	63.6	202	0.0066	30.6	32.1
	KC-24	312	71.2	228	0.0074	30.8	33.6
	LB-16	314	72.5	230	0.0074	31.1	33.6
	MA-6	313	69.0	220	0.0071	31.0	33.6
	NA-2	312	68.1	217	0.0070	31.0	32.8
	PB-15	312	80.1	256	0.0088	29.2	32.8
	PC-25	311	70.3	225	0.0076	29.6	32.1
	QC-28	312	69.0	221	0.0072	30.6	32.1
	RB-20	305	77.8	256	0.0082	31.2	33.6
	RC-27	310	71.2	230	0.0073	31.6	34.5
10,000	JC-27[a]	313	-	-	-	-	-
	JC-28	313	63.6	203	0.0068	29.8	31.6
	KC-22	311	66.3	212	0.0068	31.4	33.6
	LC-23	311	60.9	195	0.0063	31.0	32.1
	MC-25	313	73.8	236	0.0080	29.4	33.1
	NB-13	312	78.7	252	0.0084	30.1	33.1
	PC-27	312	71.2	228	0.0076	30.1	32.1
	QC-23	312	73.4	234	0.0076	31.0	33.6
	SA-3	311	69.0	221	0.0071	31.4	33.6
	SB-11	305	64.5	212	0.0069	30.5	33.8
20,000	JB-11	310	62.7	202	0.0063	32.1	34.5
	LC-31	304	70.7	232	0.0074	31.4	33.6
	MB-11	306	76.5	249	0.0072	34.5	36.3
	NA-6	313	66.3	211	0.0067	31.5	33.6
	PB-17	312	73.0	234	0.0070	32.0	33.6
	QB-13	314	65.4	208	0.0068	30.6	33.6
	QC-22	312	61.4	196	0.0063	31.2	33.6
	RA-7	312	60.5	194	0.0064	30.4	33.6
	RC-22	312	62.3	199	0.0062	32.1	33.6
	SC-27	308	68.9	223	0.0070	31.9	34.5
28,000	JB-18	312	63.6	203	0.0066	30.8	32.1
	KB-17	311	69.0	221	0.0076	29.1	32.1
	LB-19	311	74.3	239	0.0075	31.9	34.0
	LC-26	312	75.2	241	0.0083	29.0	32.2
	MB-15	312	83.2	267	0.0096	27.9	33.3
	NB-18	313	66.7	213	0.0068	31.3	33.6
	PA-7	312	71.2	228	0.0076	30.1	32.1
	RC-25	311	66.7	215	0.0070	30.8	32.8
	RC-31	307	75.6	246	0.0078	31.6	33.6
	SB-17	309	60.0	194	0.0064	30.3	32.8

a = Failed on loading due to operator error.

APPENDIX D

Damage Growth Characteristics

Under Fatigue Loading

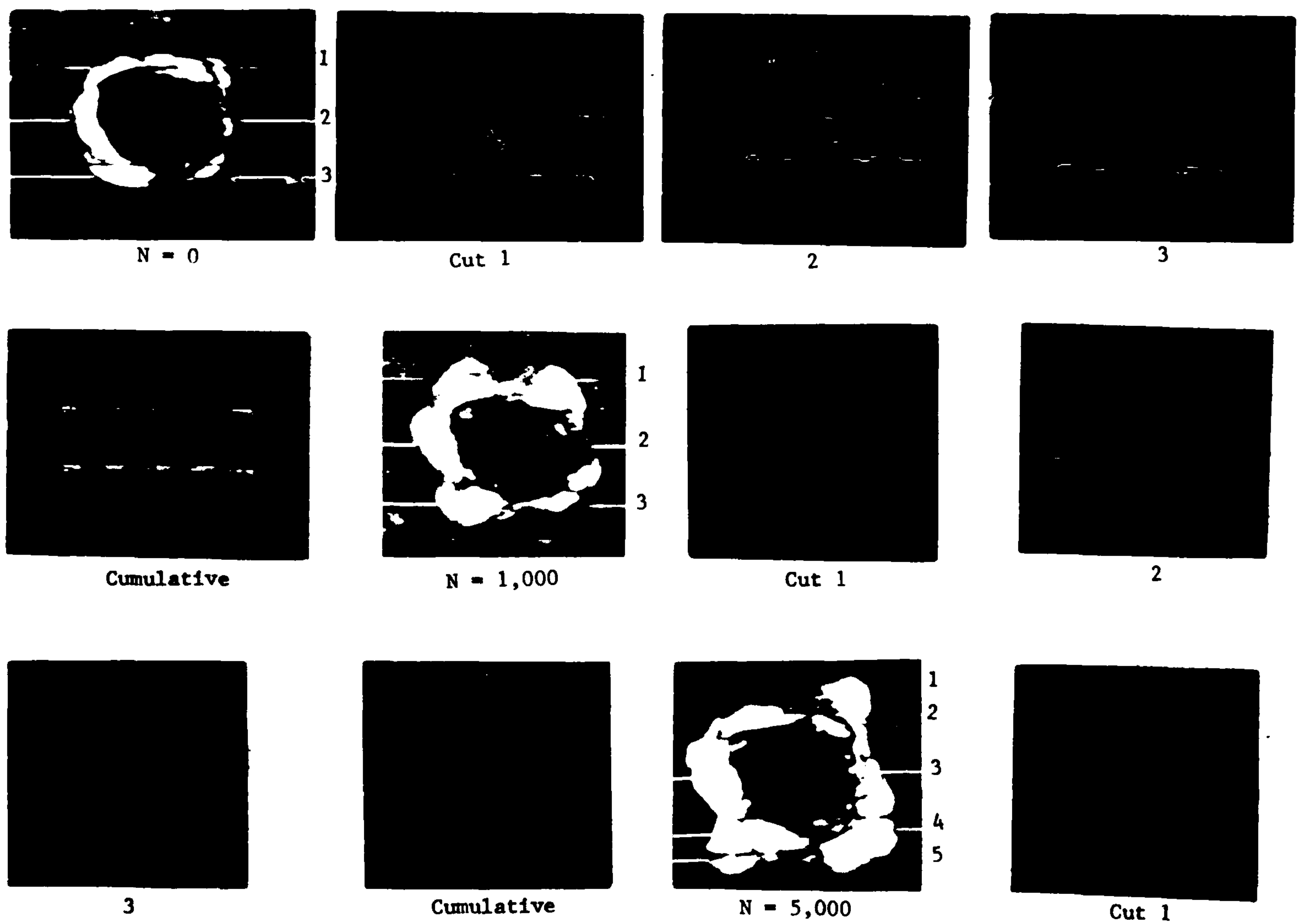


Figure D1a: Damage Growth Characteristics of 24-Ply, 67% 0^{o} Fiber Short Lived Specimens (FA-3 N_f = 47,846)

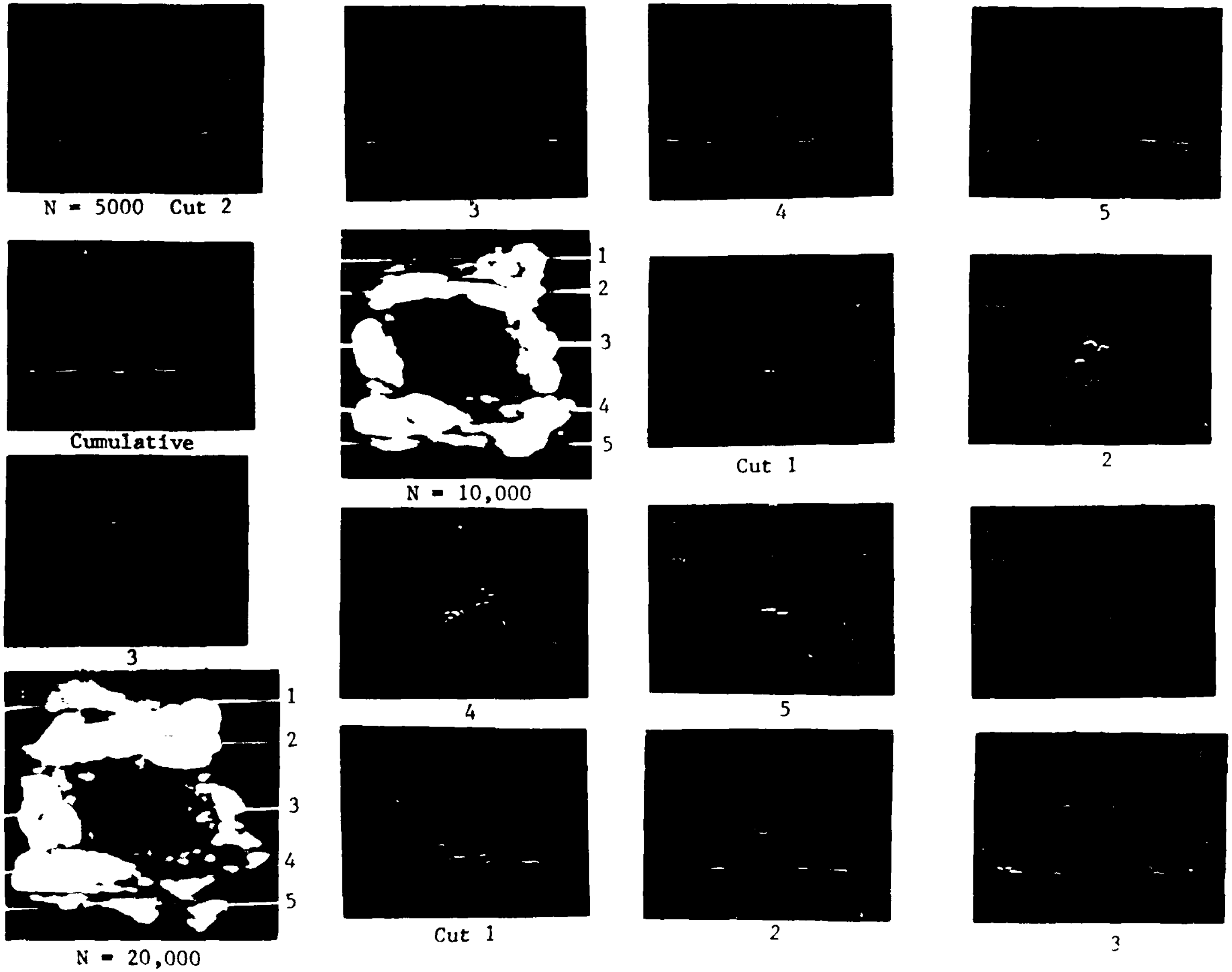


Figure D1b: Damage Growth Characteristics of 24-Ply , 67% 0° Fiber Short Lived Specimens (FA-3 N_f = 47,846)

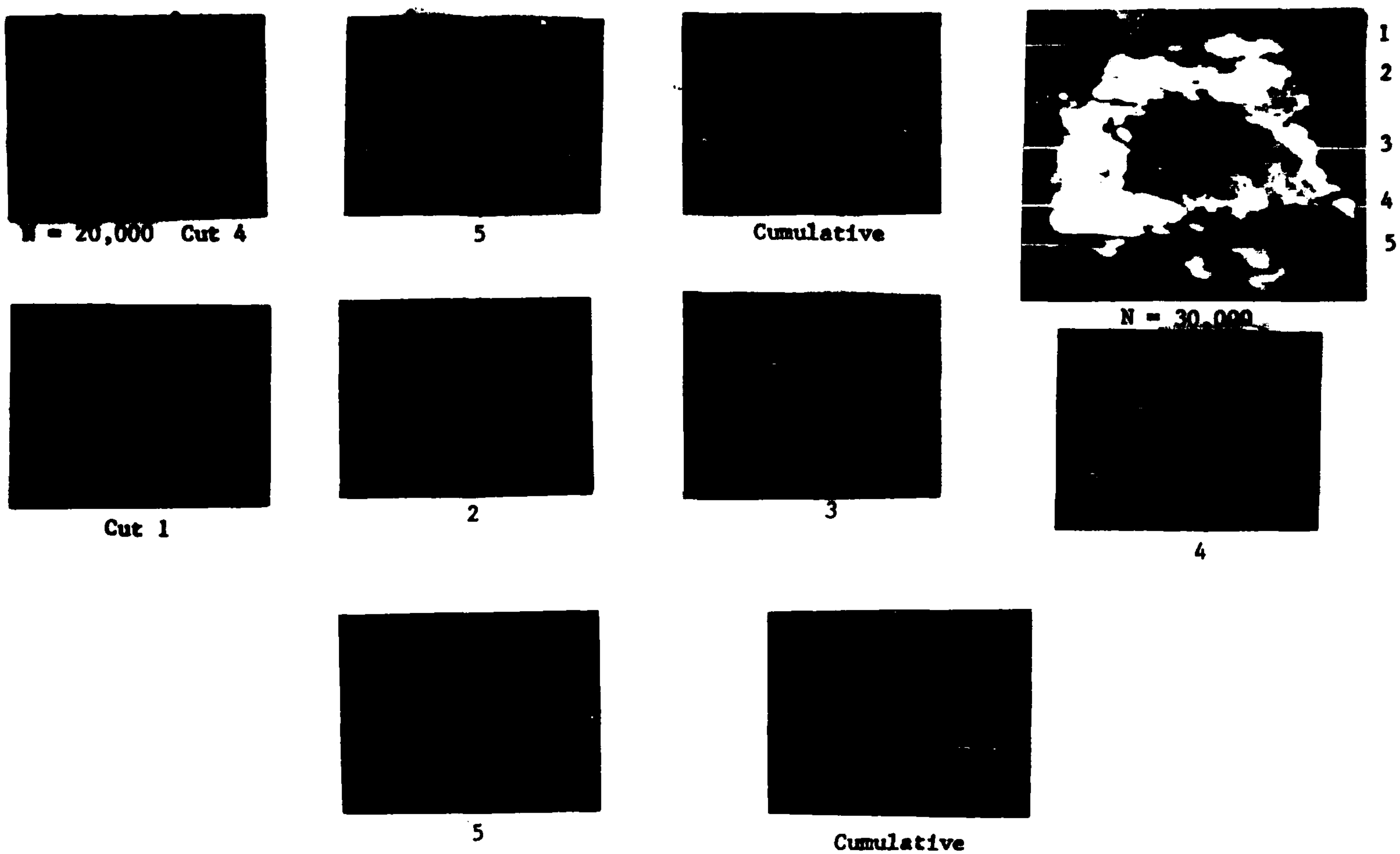


Figure D1c: Damage Growth Characteristics of 24-Ply, 67% 0° Fiber Short Lived Specimens (FA-3 N_f = 47,846)

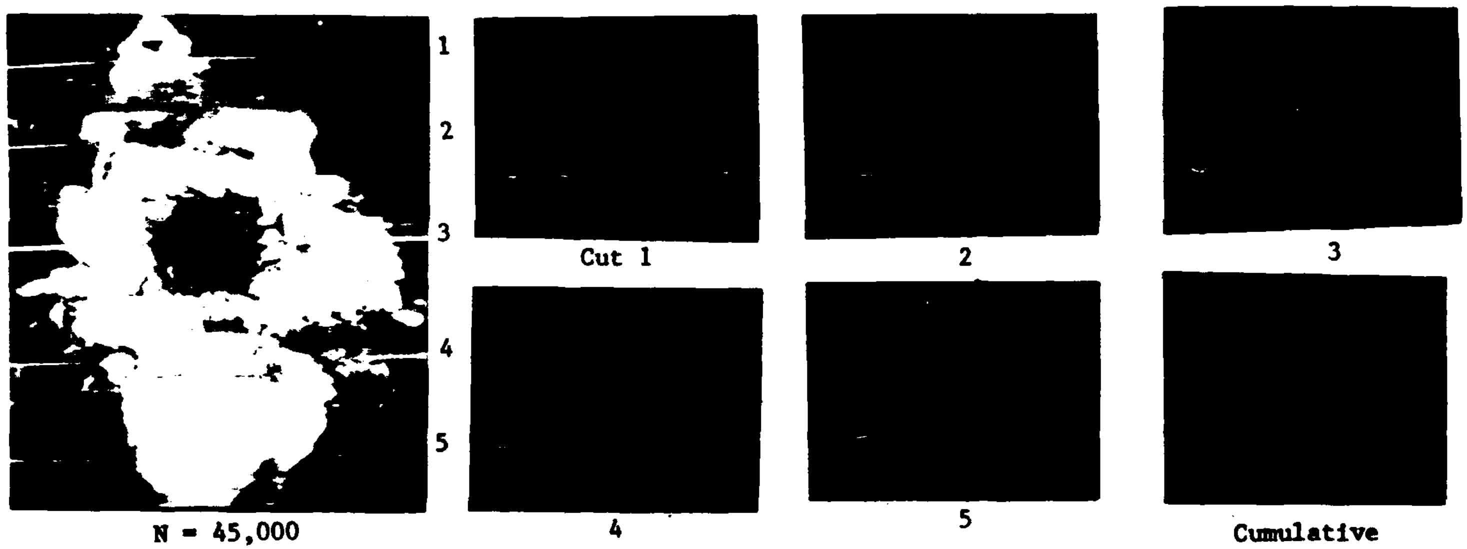


Figure D1d: Damage Growth Characteristics of 24-Ply , 67% 0^{o} Fiber Short Lived Specimens (FA-3 N_f = 47,846)

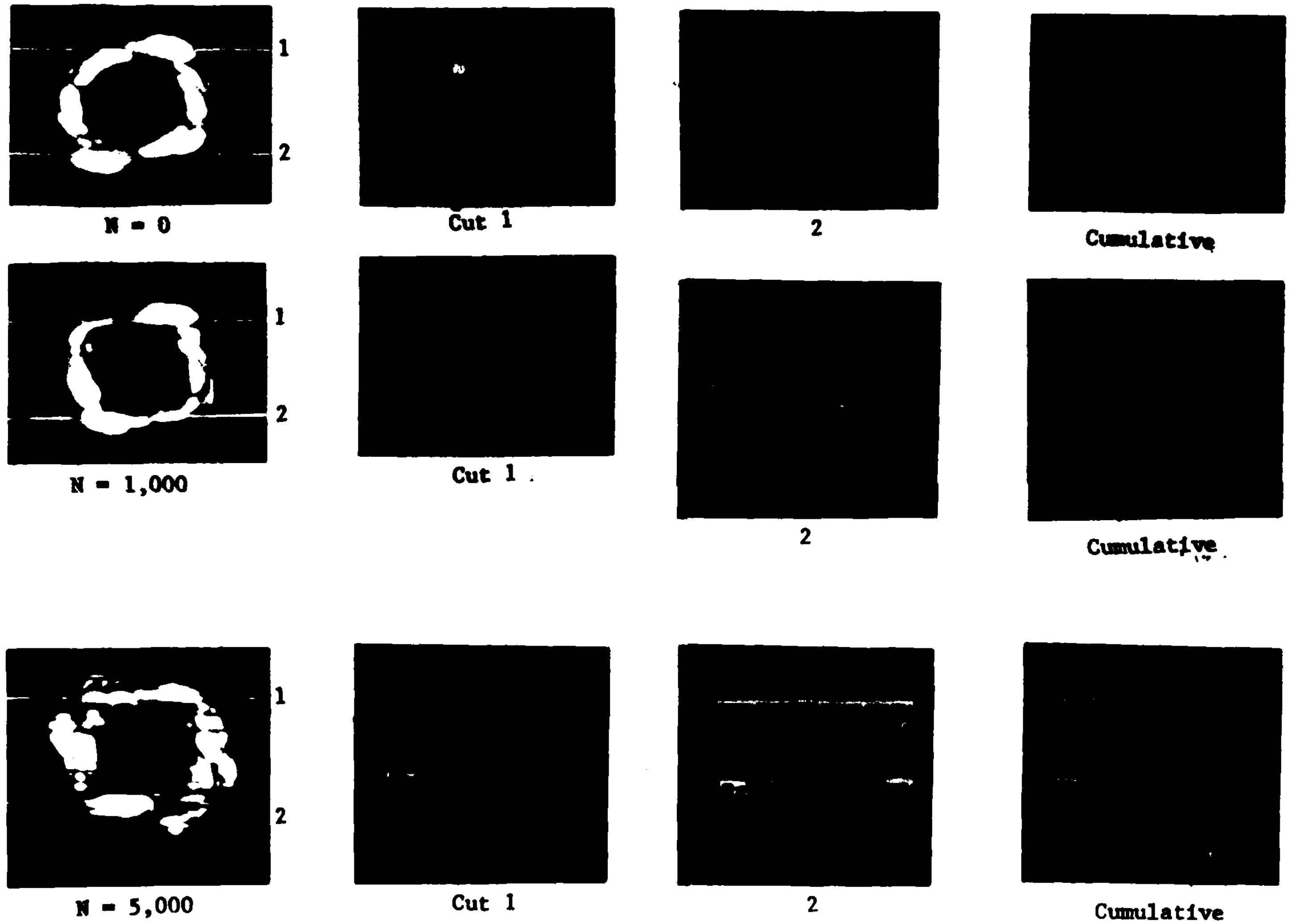


Figure D2a: Damage Growth Characteristics of 24-Ply , 67% 0^o Fiber Long Lived Specimens (HC-26 N_f = 448,633)

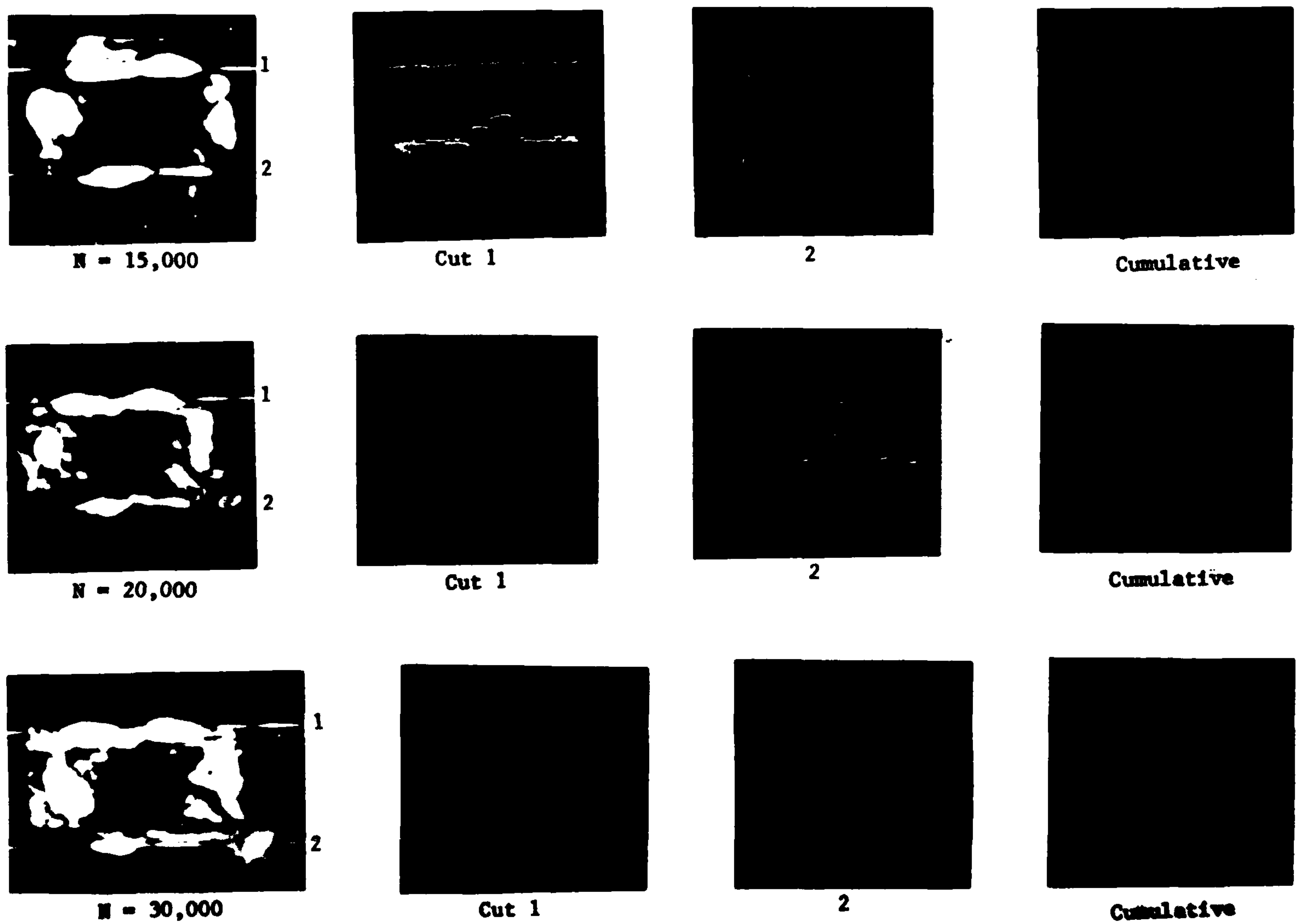


Figure D2b: Damage Growth Characteristics of 24-Ply , 67% 0^{o} Fiber Long Lived Specimens (HC-26 N_f = 448,633)

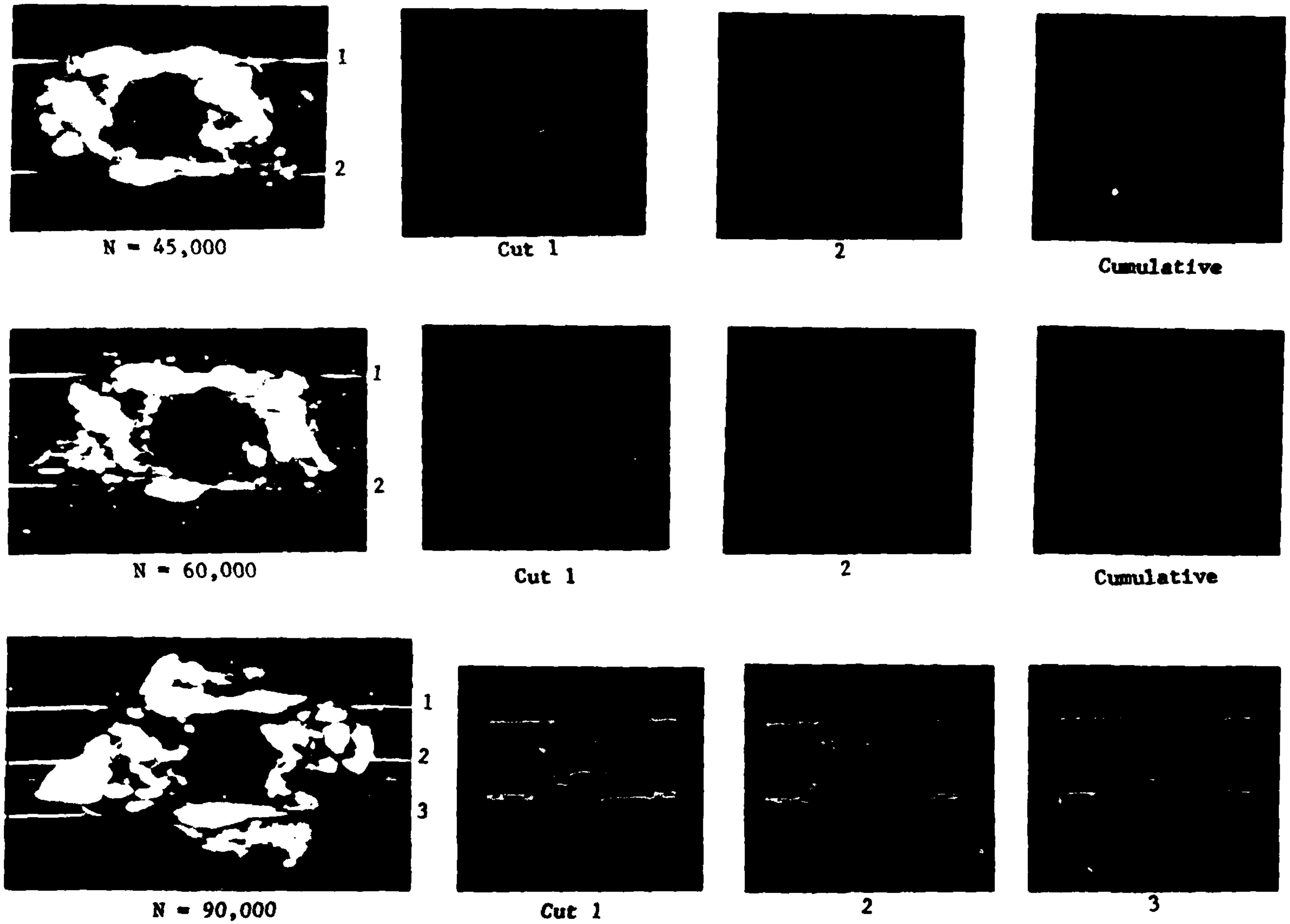


Figure D2c: Damage Growth Characteristics of 24-Ply , 67% 0^{o} Fiber Long Lived Specimens (HC-26 N_f = 448,633)

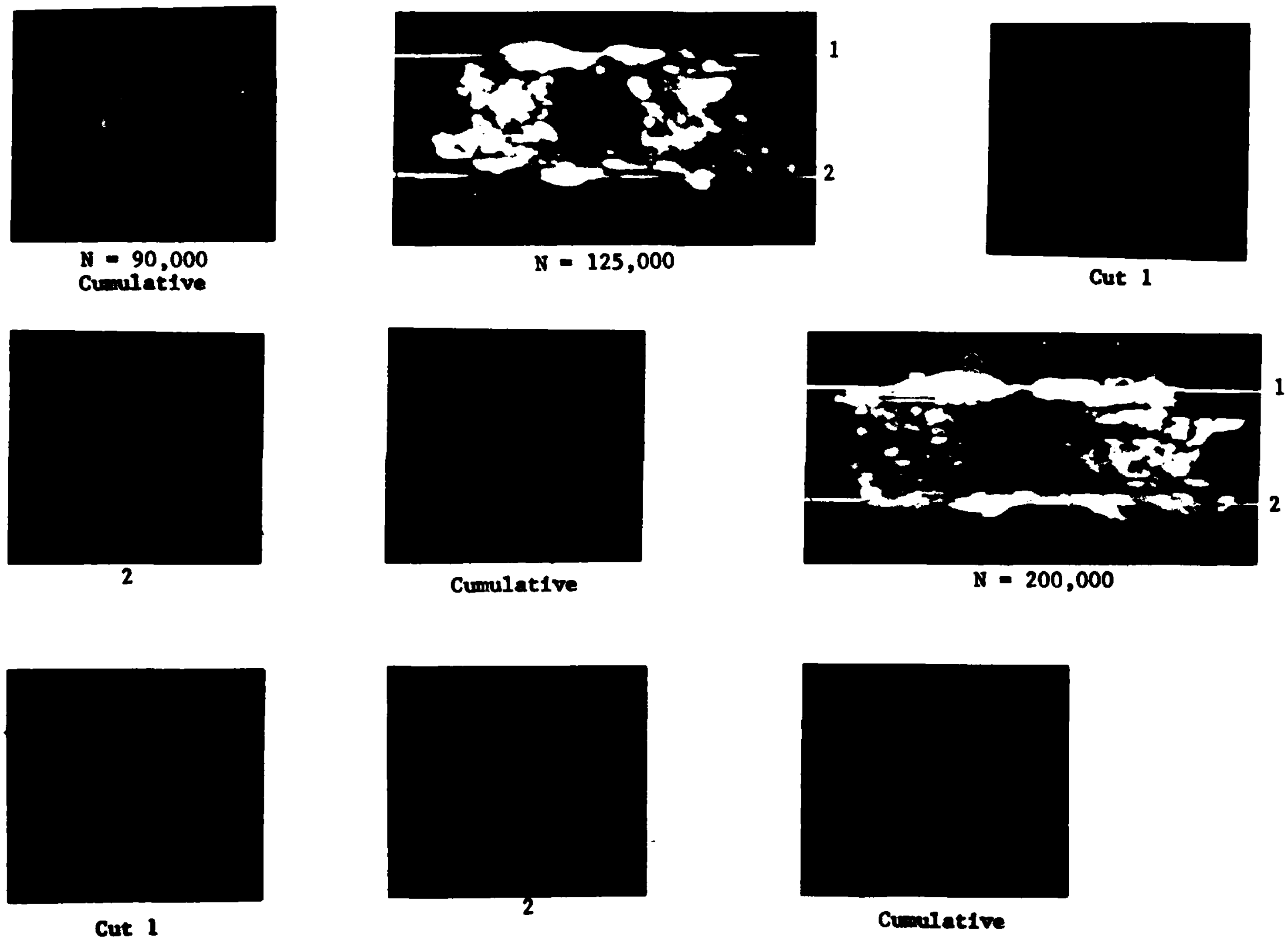


Figure D2d: Damage Growth Characteristics of 24-Ply , 67% 0° Fiber Long Lived Specimens (HC-26 N_f = 448,633)

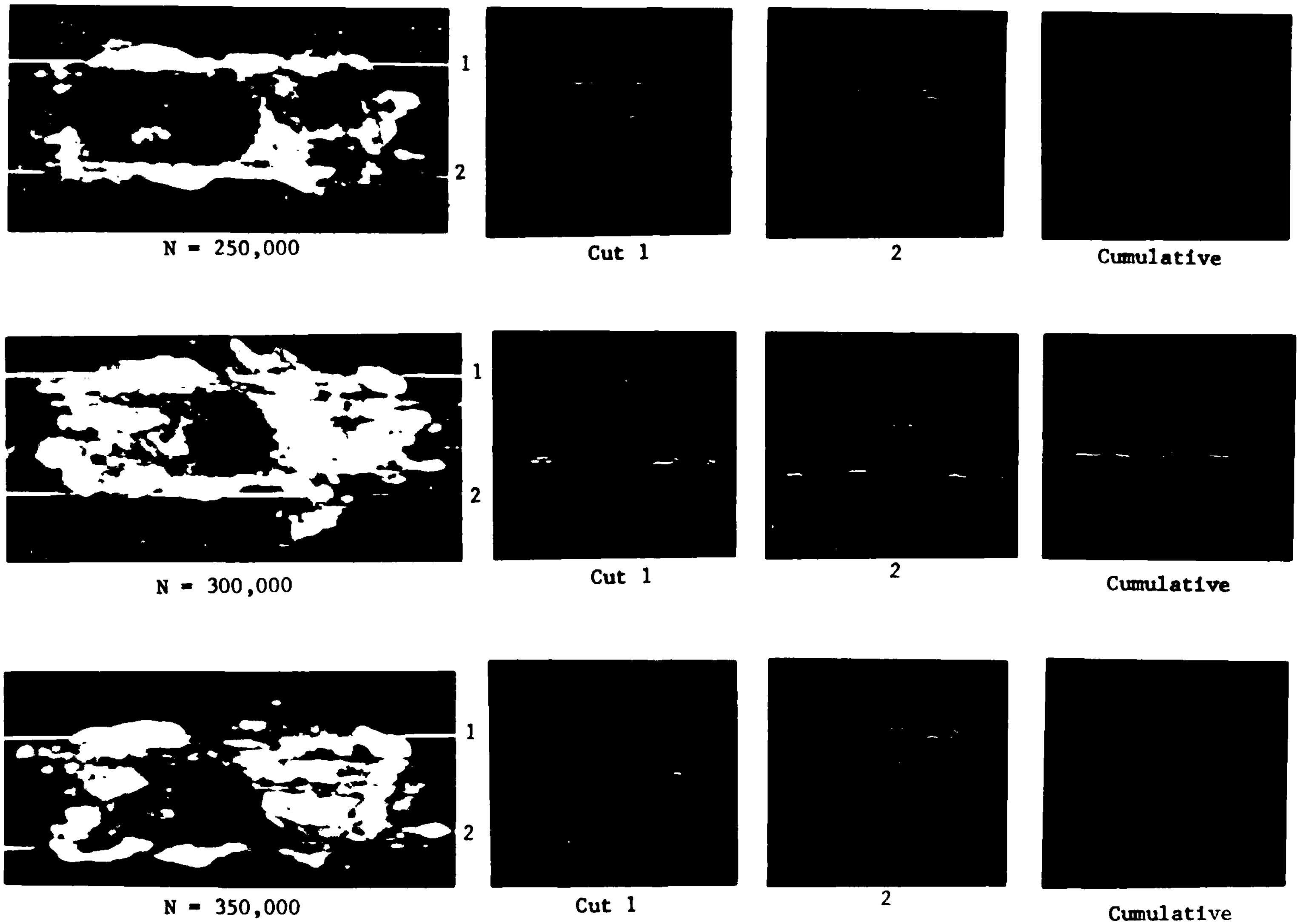


Figure D2e: Damage Growth Characteristics of 24-Ply , 67% 0° Fiber Long Lived Specimens (HC-26 N_f = 448,633)

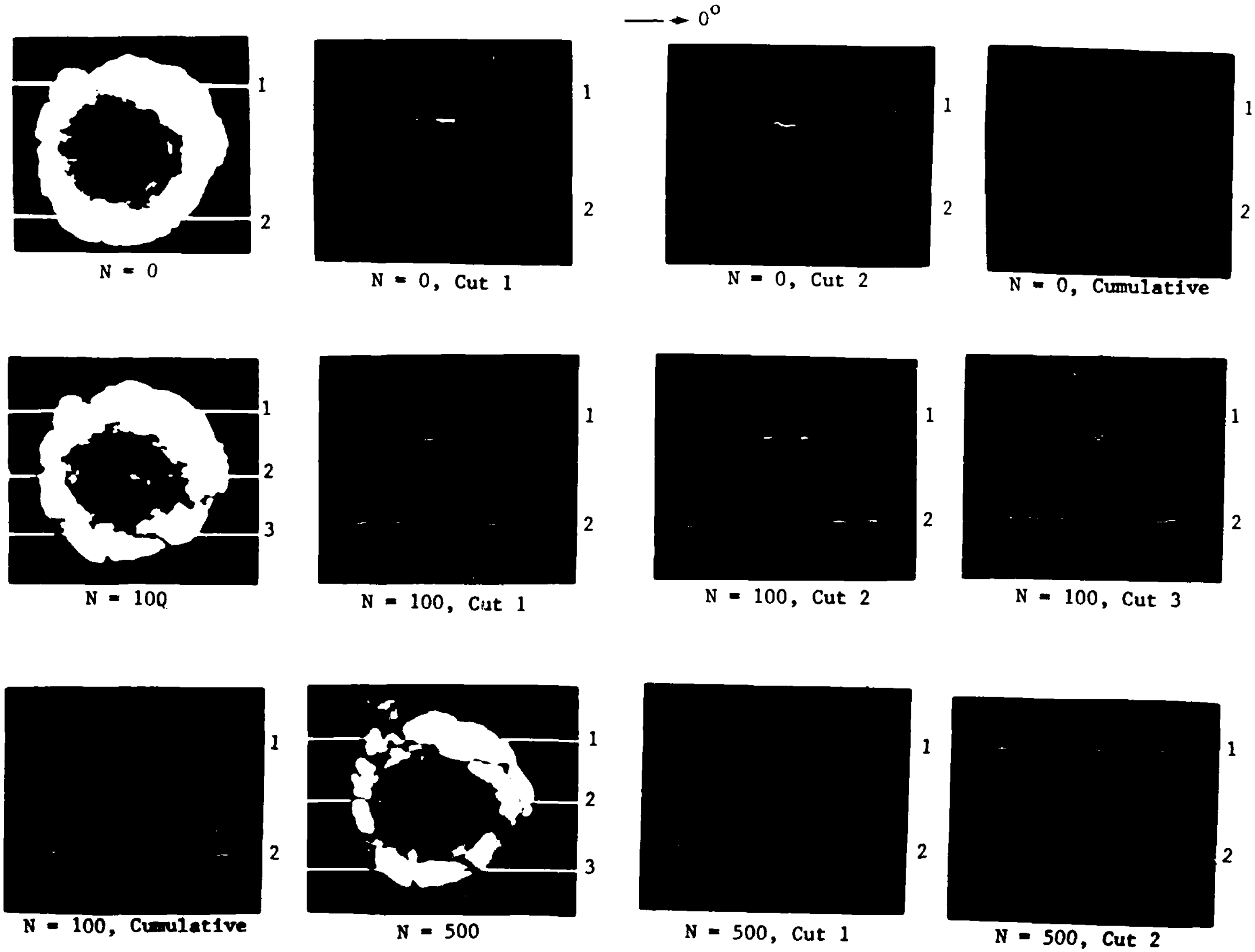


Figure D3a: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, N_f = 27,673)

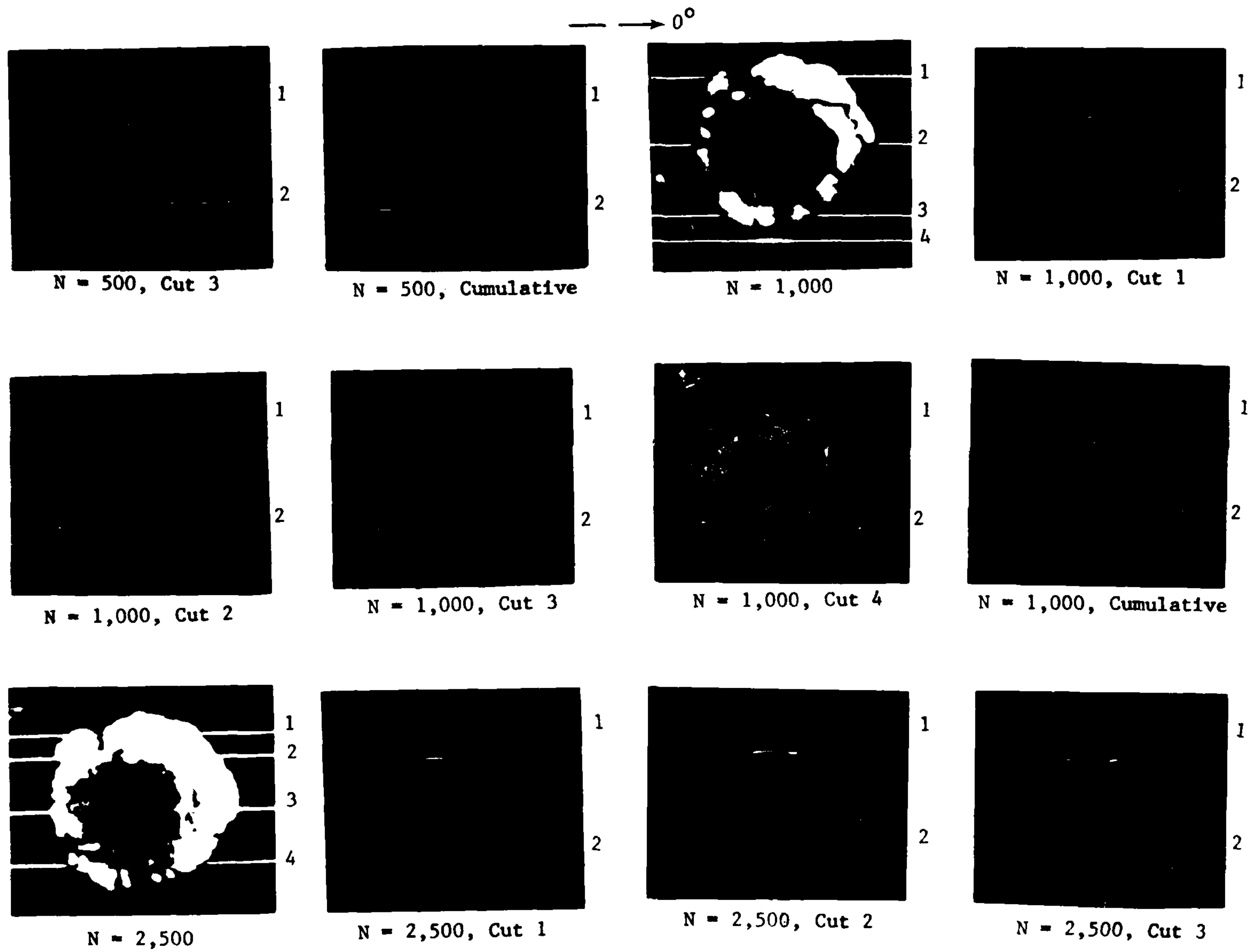


Figure D3b: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, N_f = 27,673)

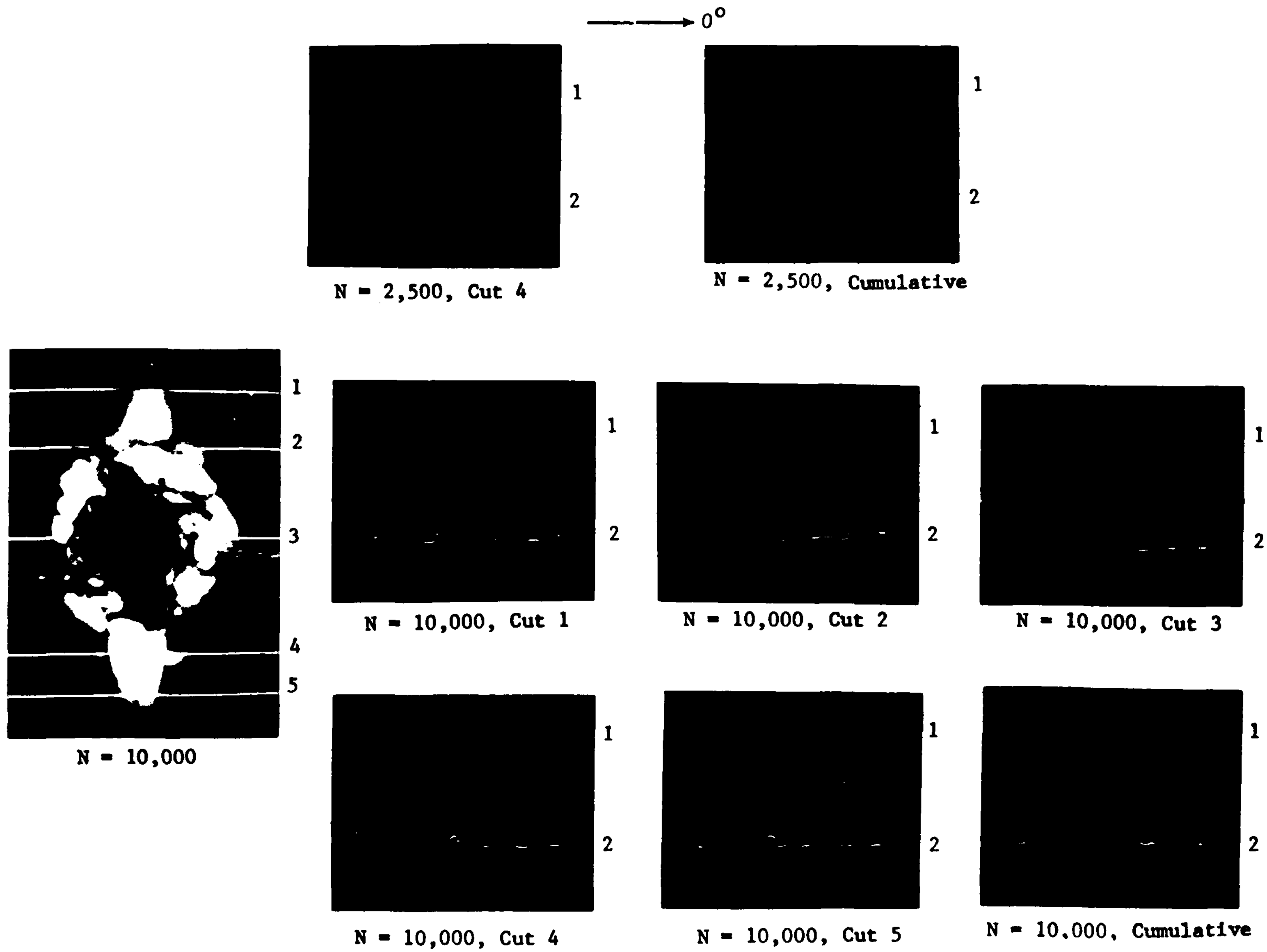


Figure D3c: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, N_f = 27,673)

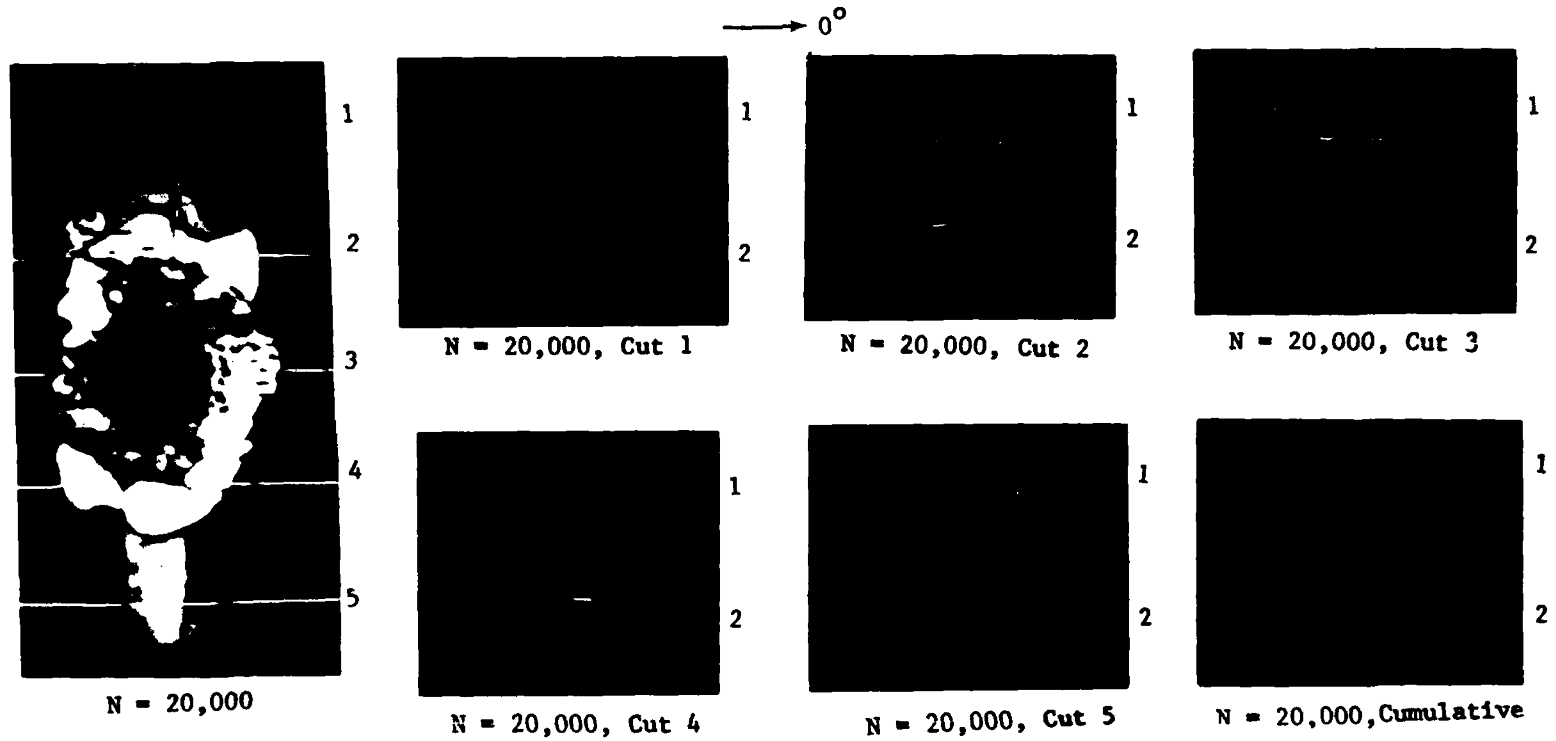


Figure 3Dd: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, N_f = 27,673)

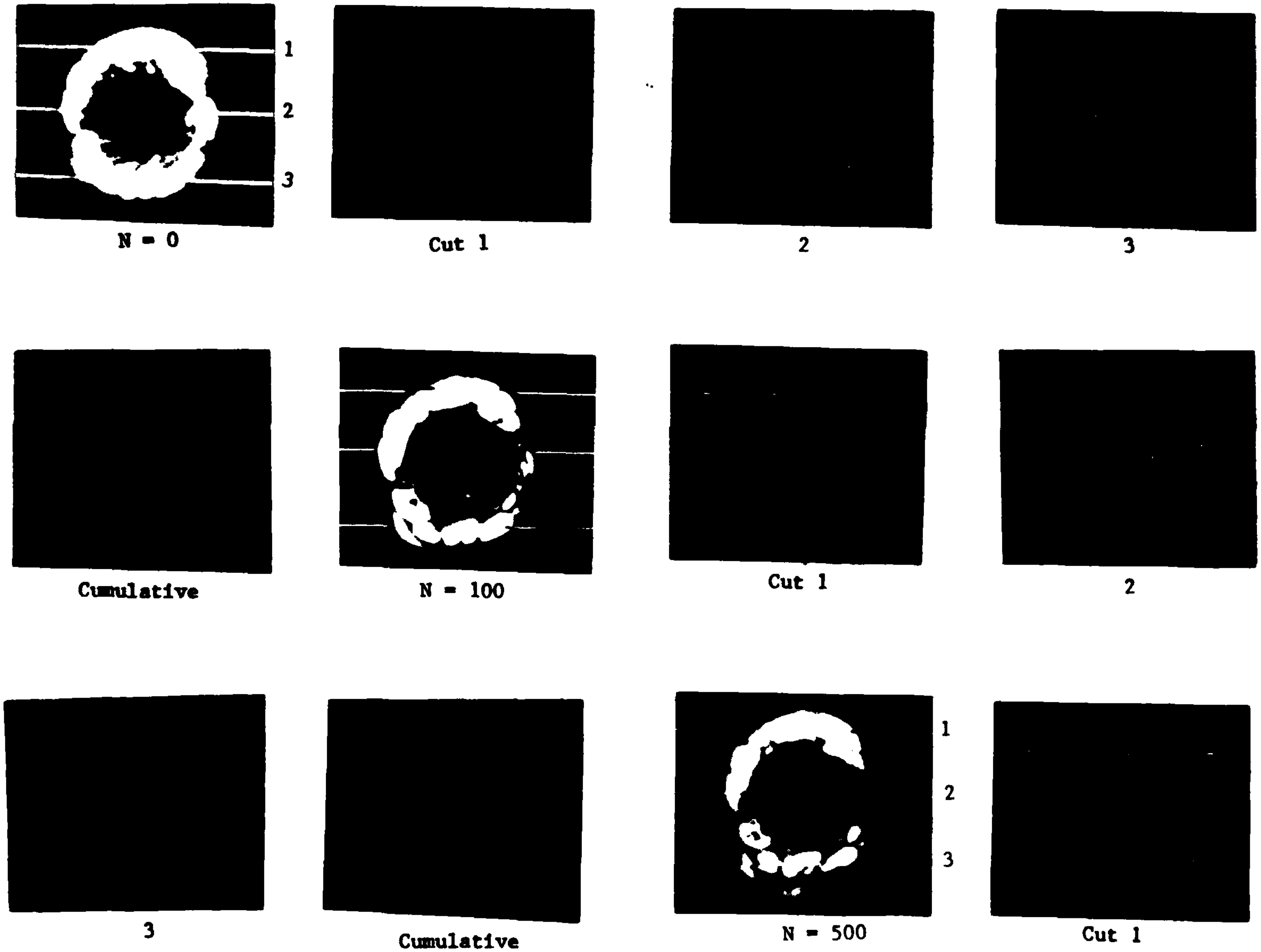


Figure D4a: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 N_f = 188,907)

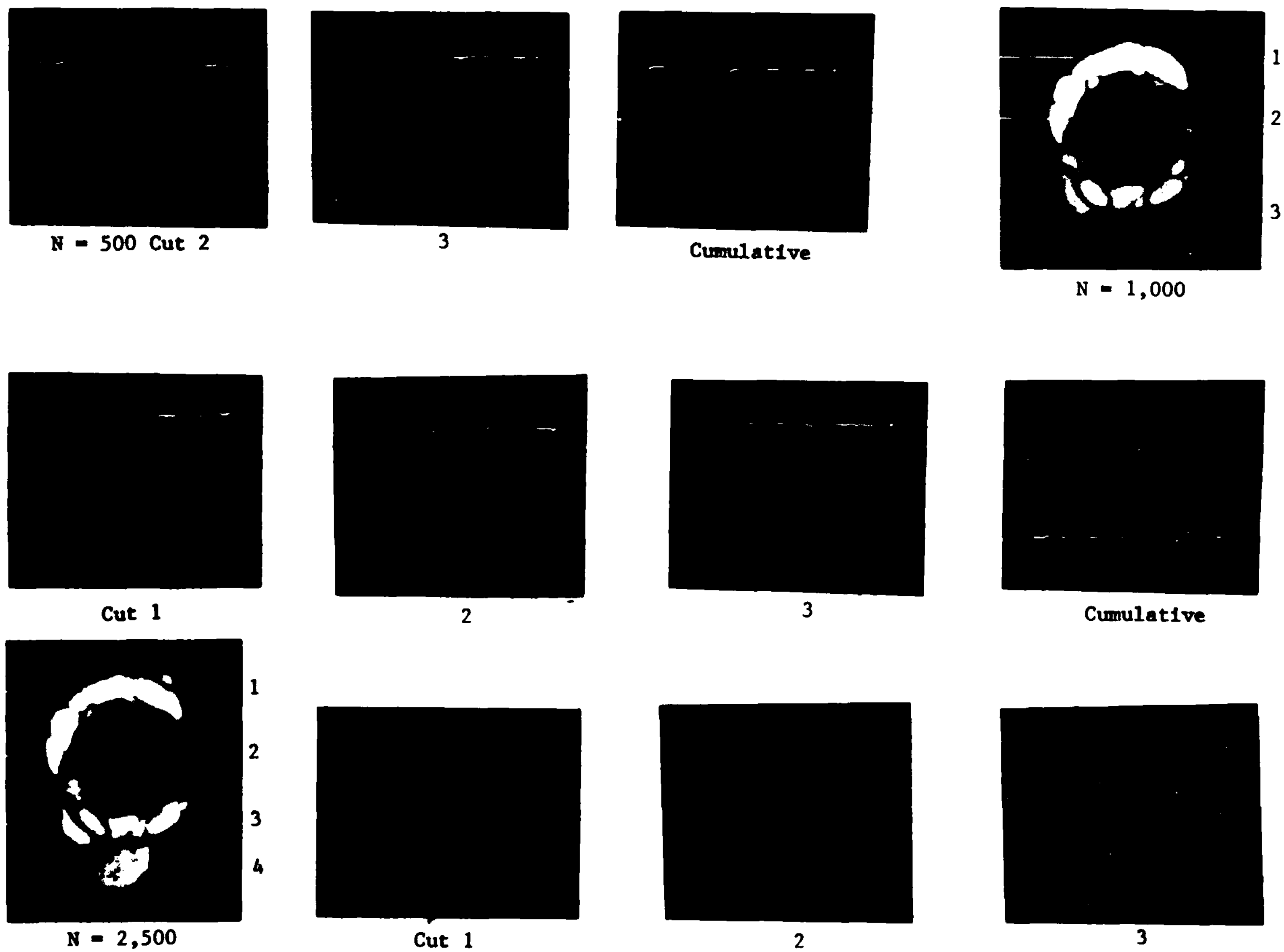


Figure D4b: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 N_f = 188,907)

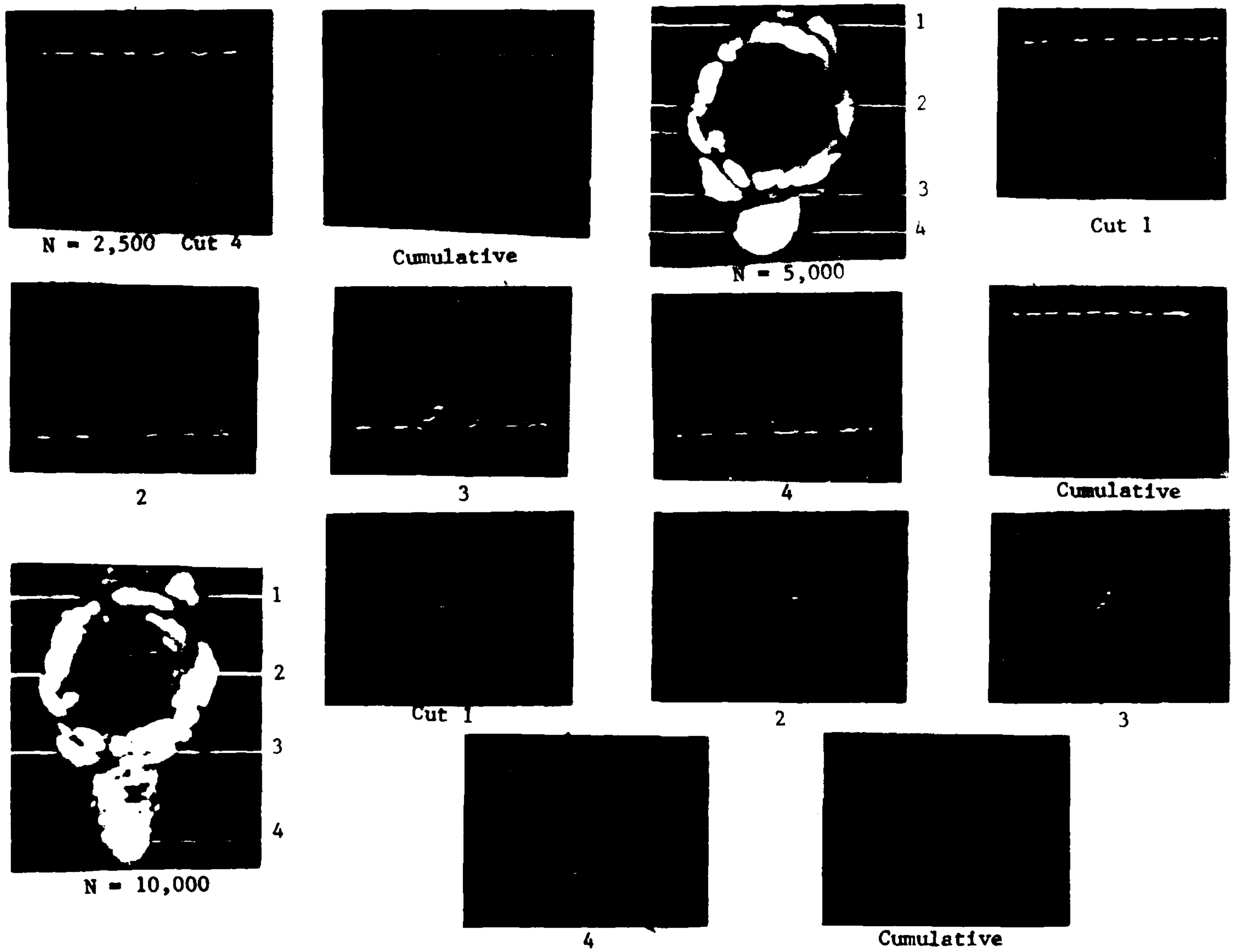


Figure D4c: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 N_f = 188,907)

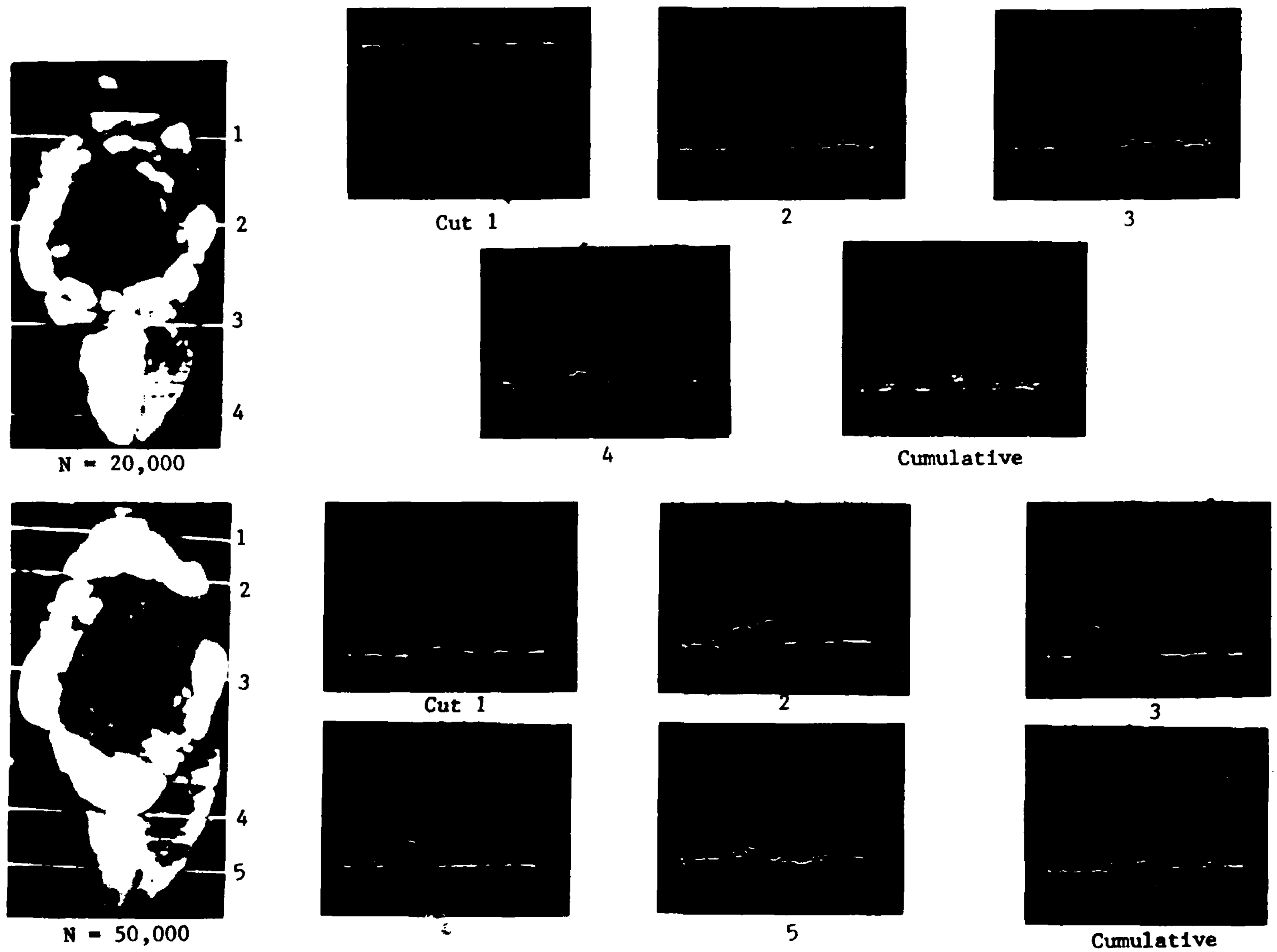


Figure D4d: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 N_f = 188,907)

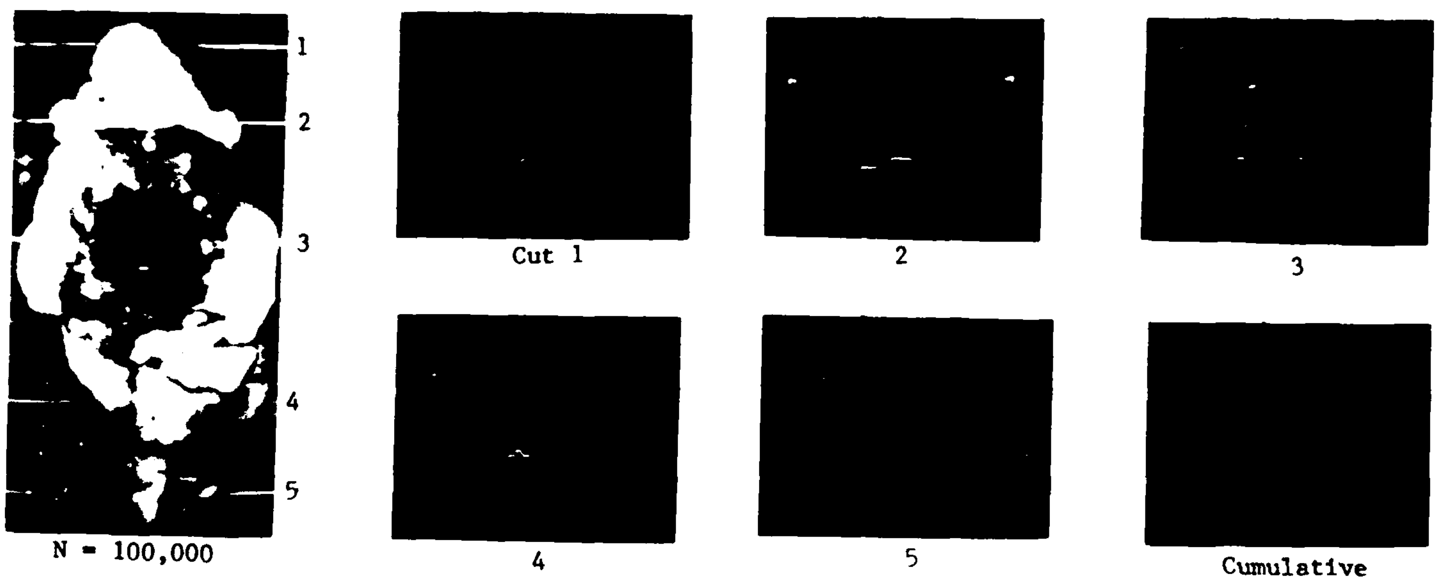


Figure D4e: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 N_f = 188,907)

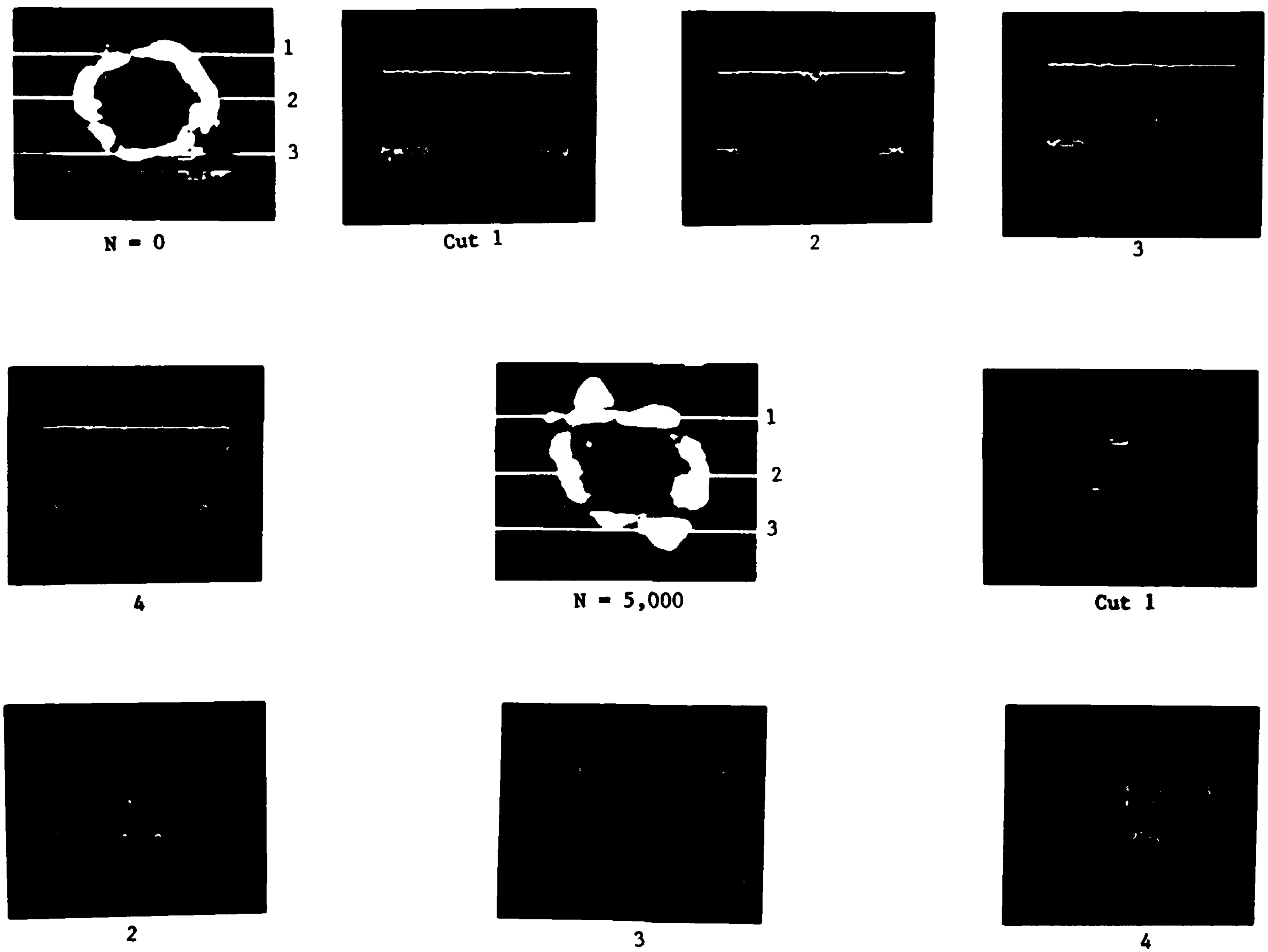


Figure D5a: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, N_f = 569,499)

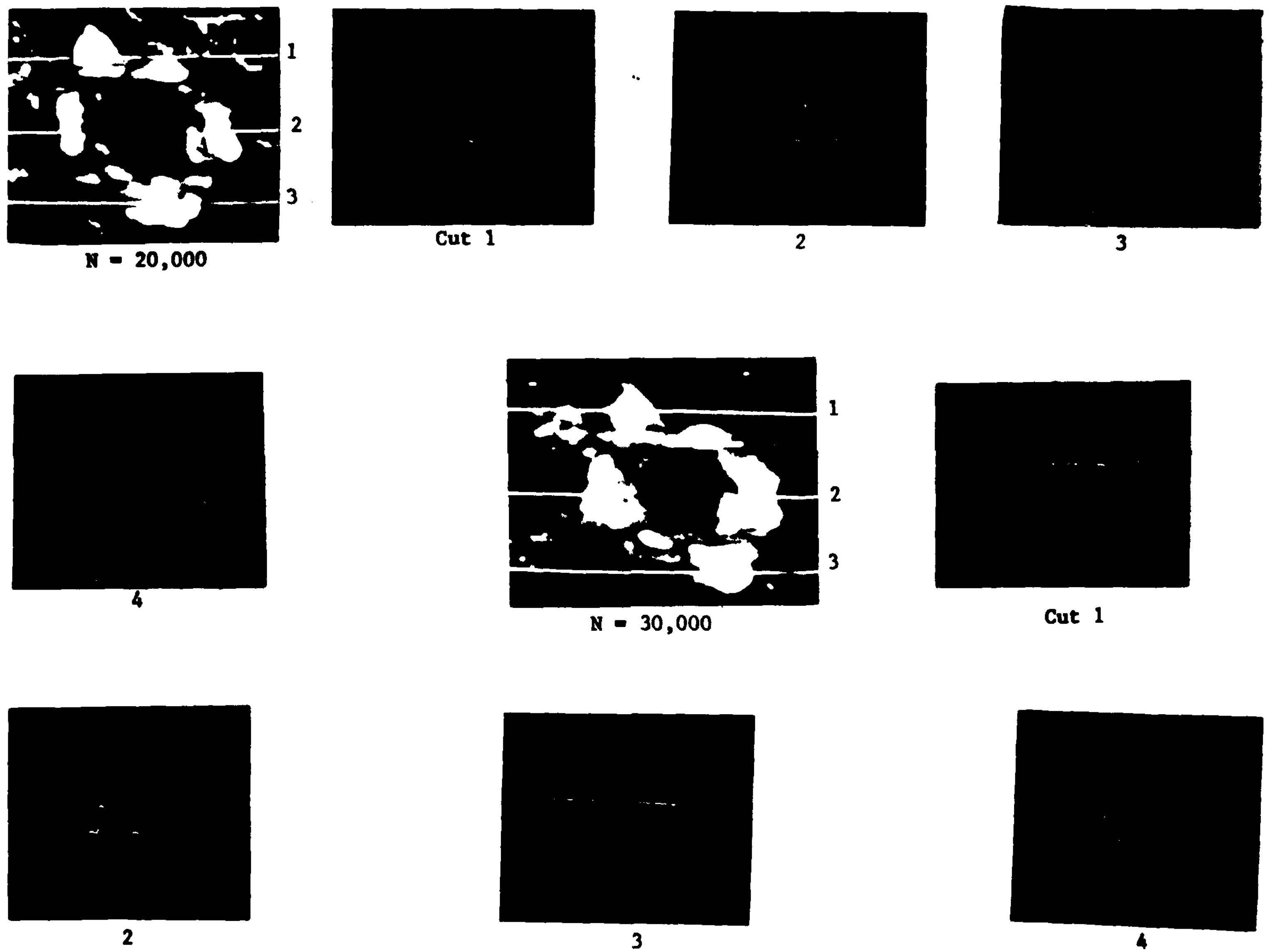


Figure D5b: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, N_f = 569,499)

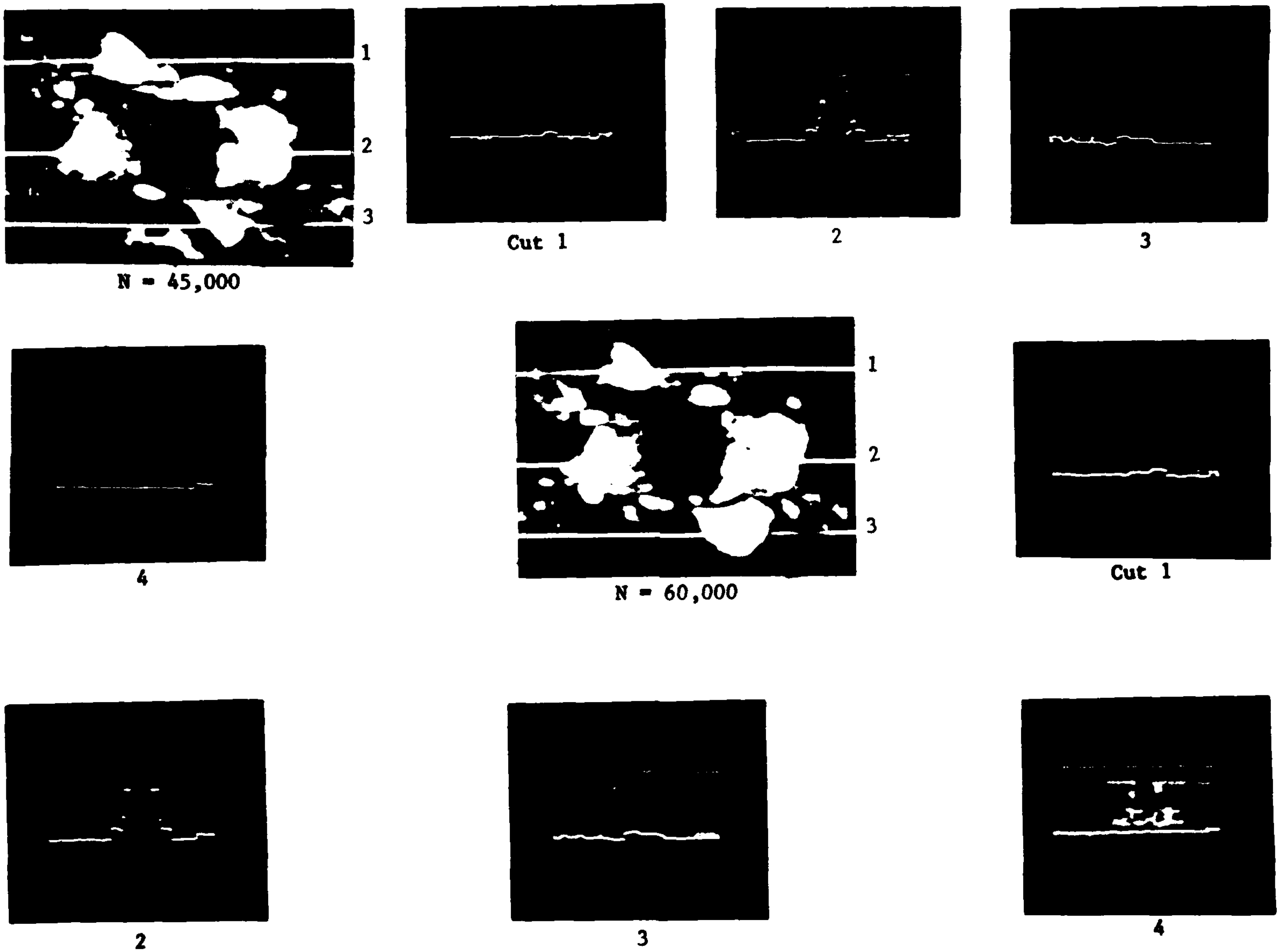


Figure D5c: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, N_f = 569,499)

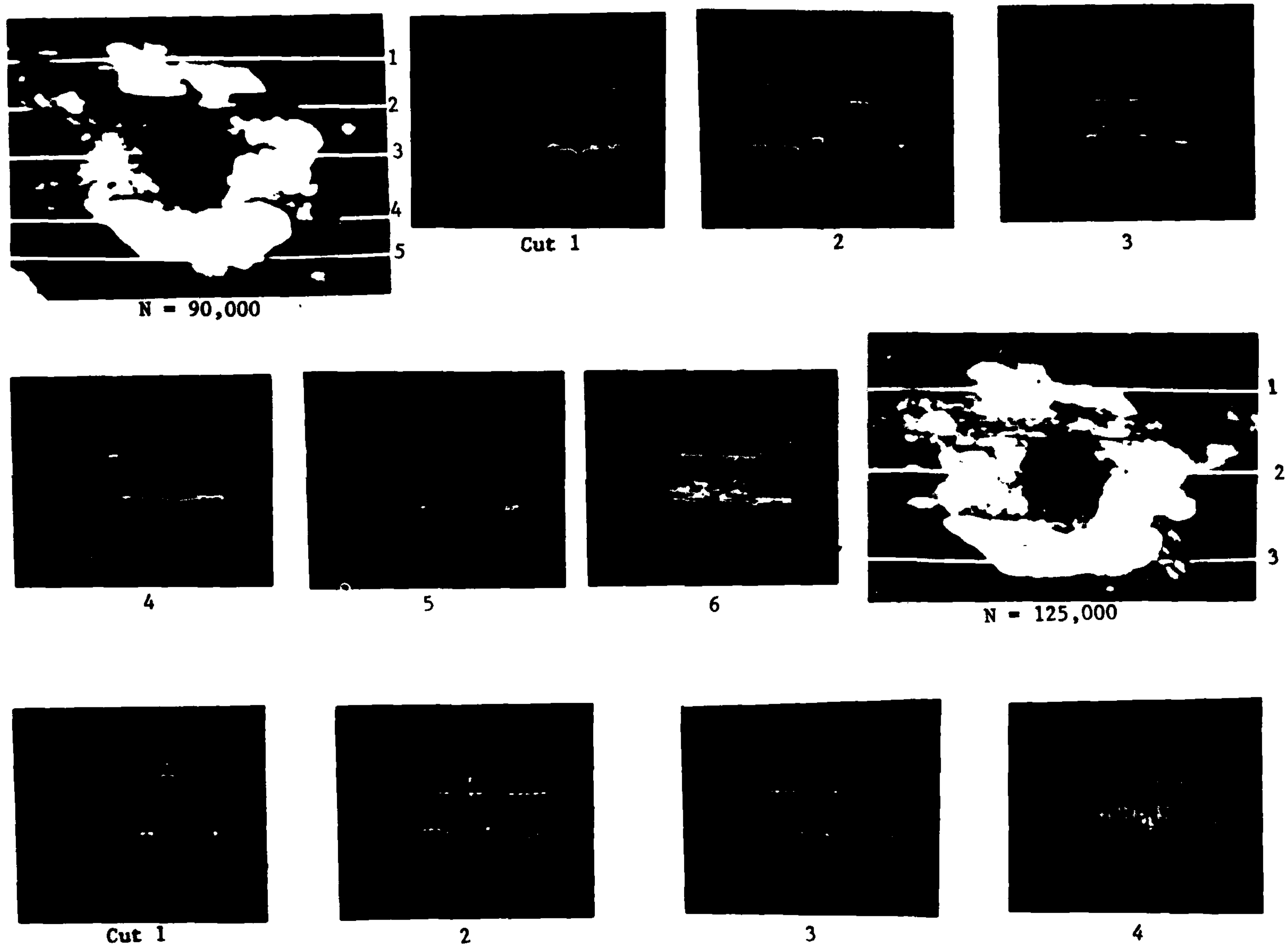


Figure D5d: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, N_f = 569,499)

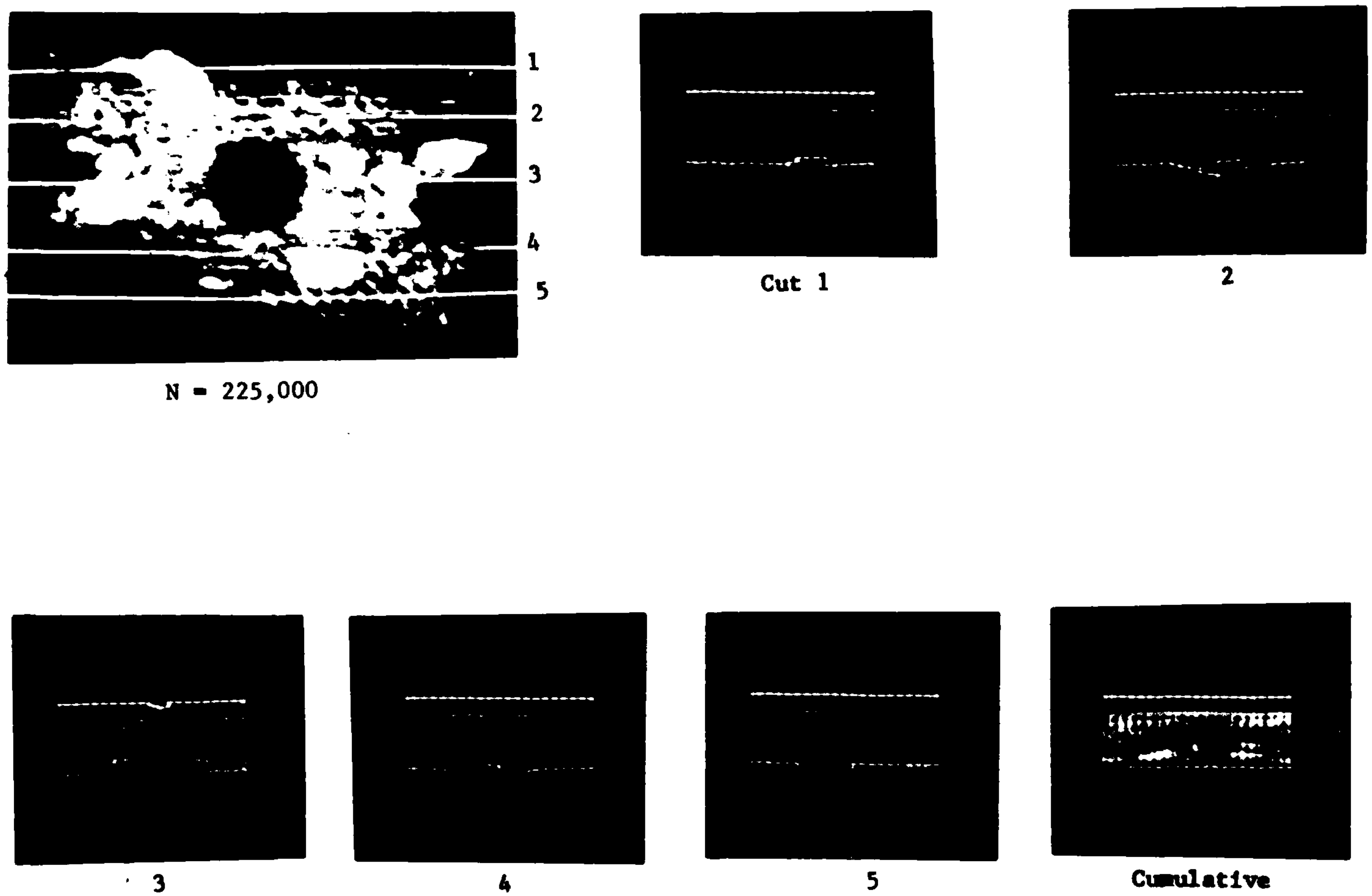


Figure D5e: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, N_f = 569,499)

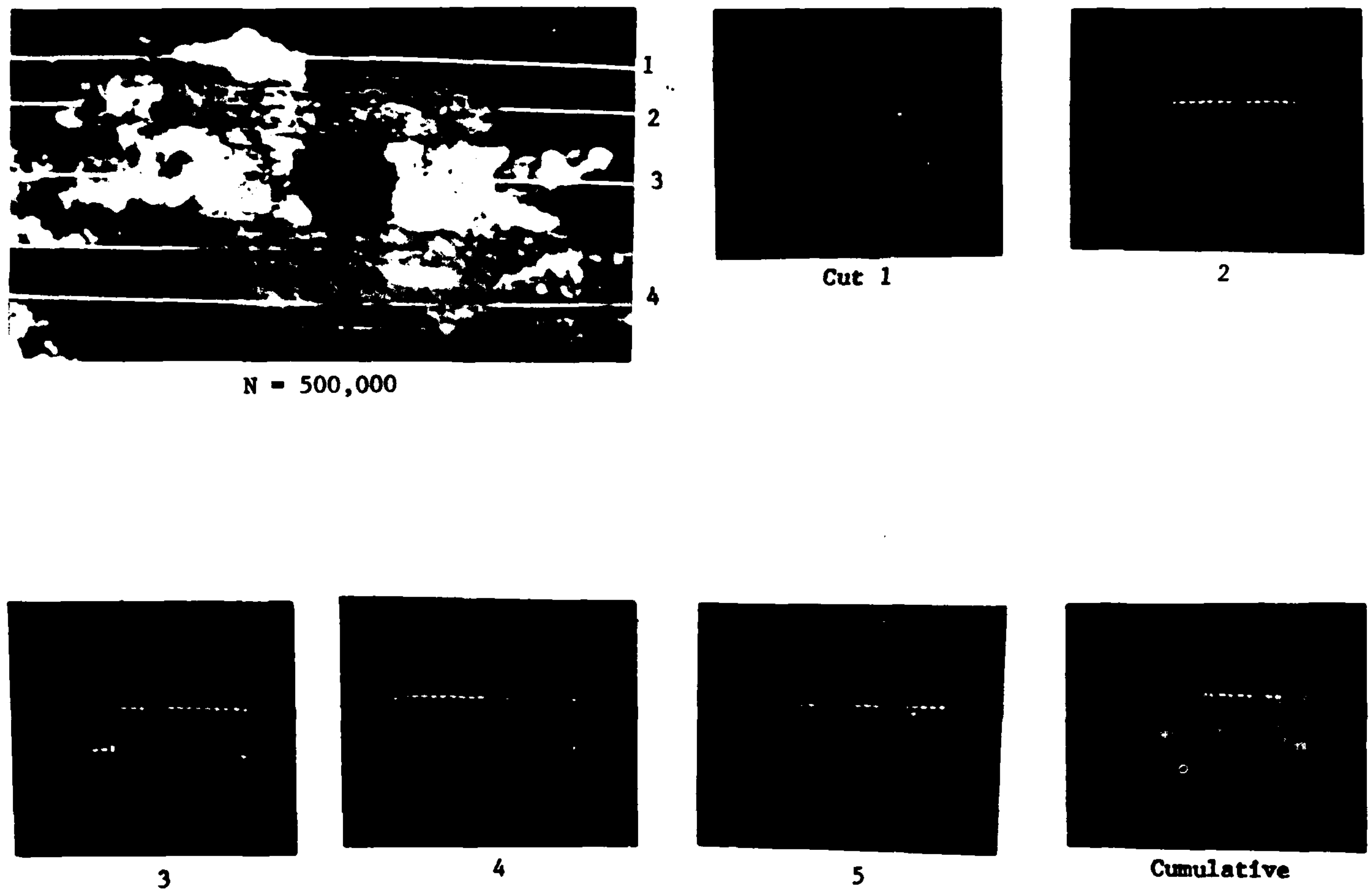


Figure D5f: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, N_f = 569,499)

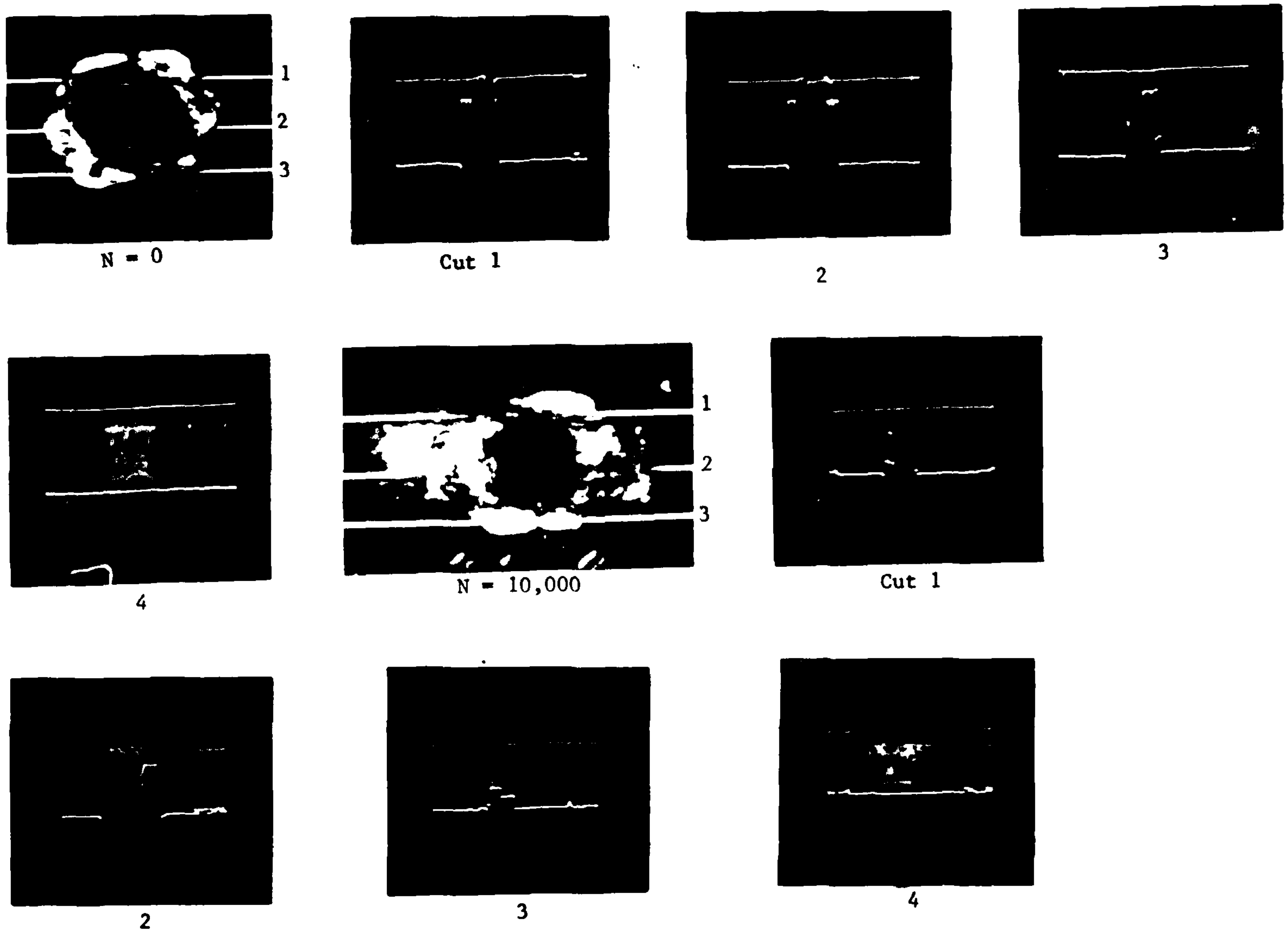


Figure D6a: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, R = -0.3 (AB-11, 12 x 10^6 without failure)

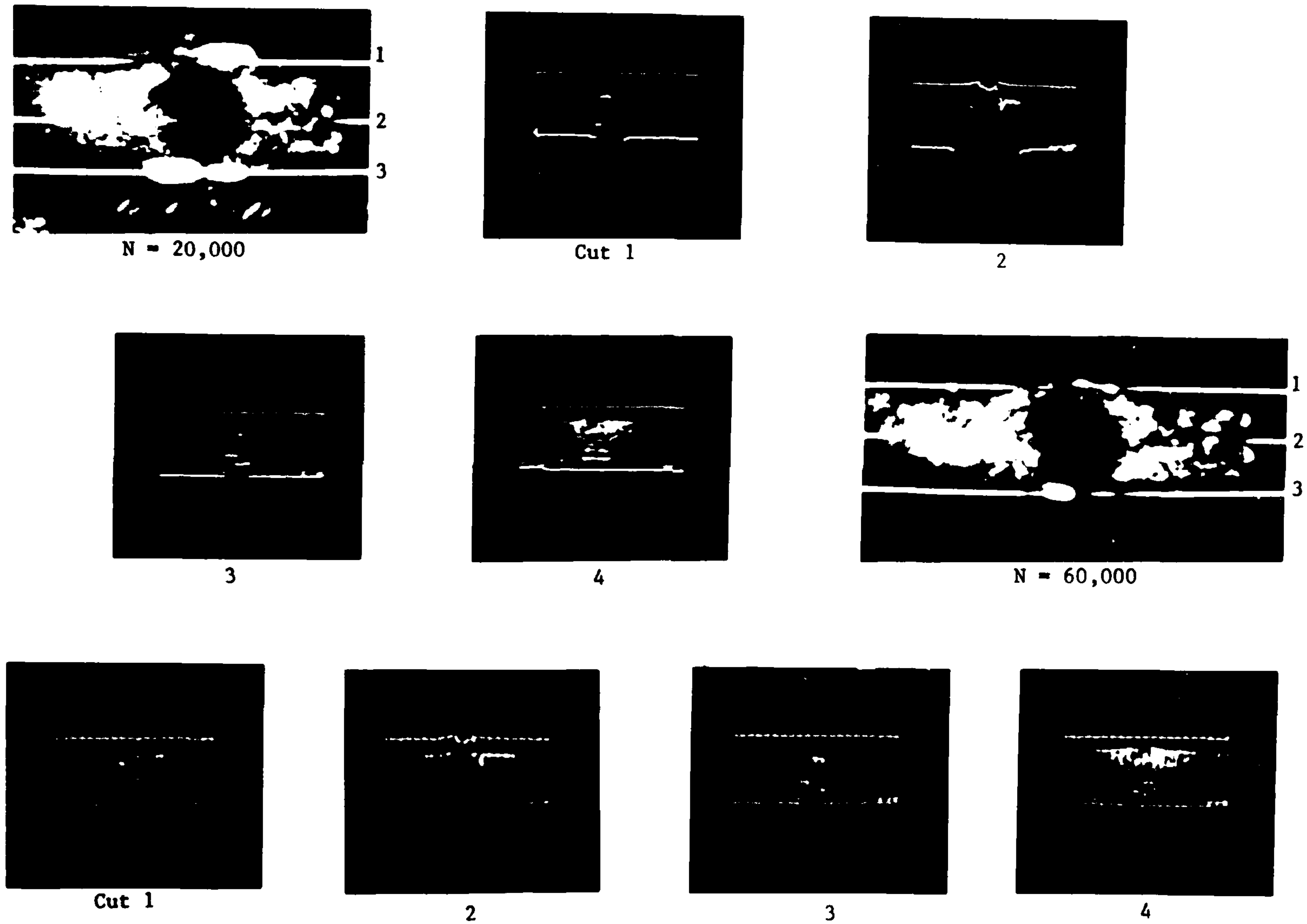


Figure D6b: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, R = -0.3 (AB-11, 12 x 10^6 without failure)

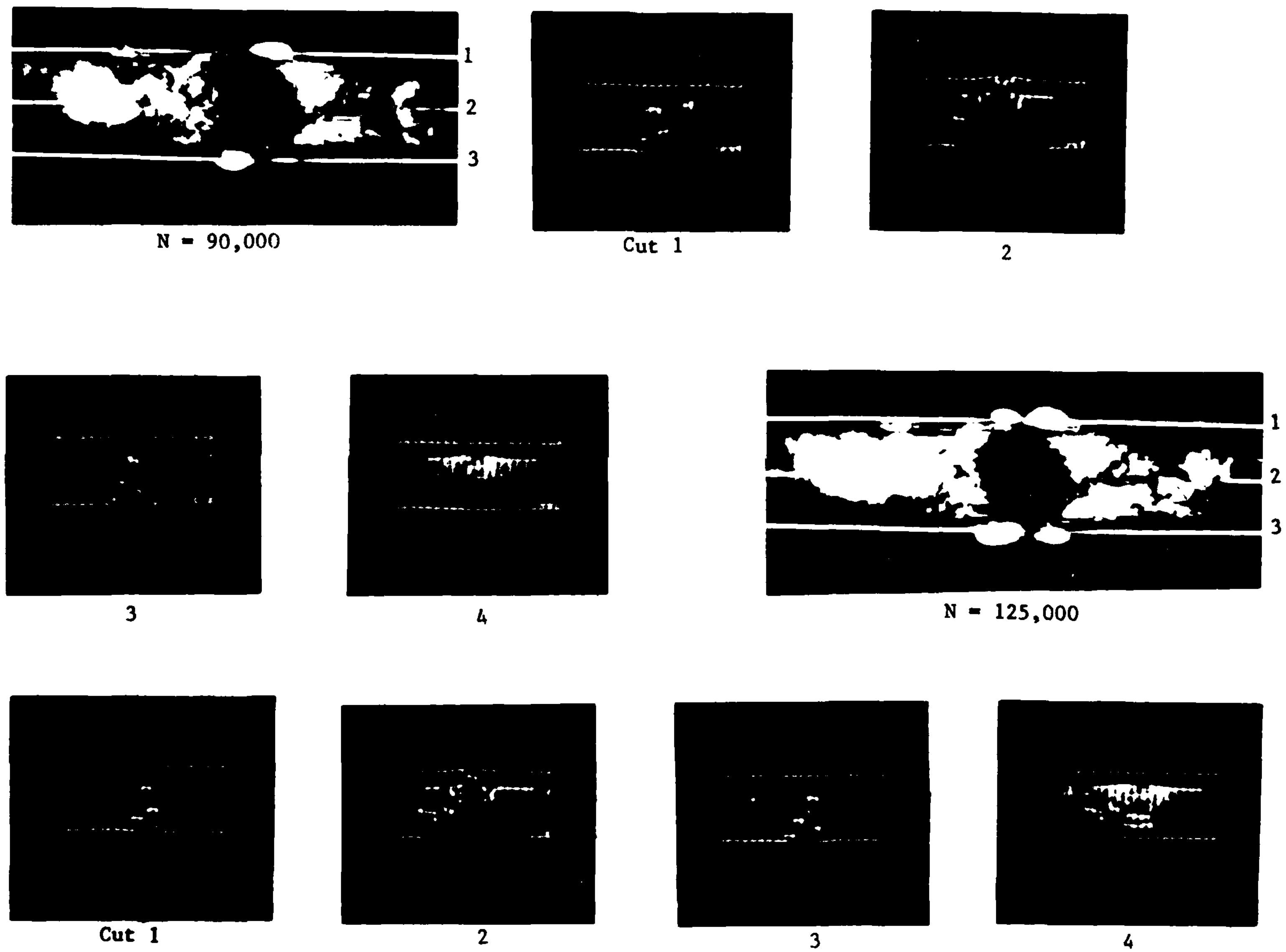


Figure D6c: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, R = -0.3 (AB-11, 12 x 10^6 without failure)

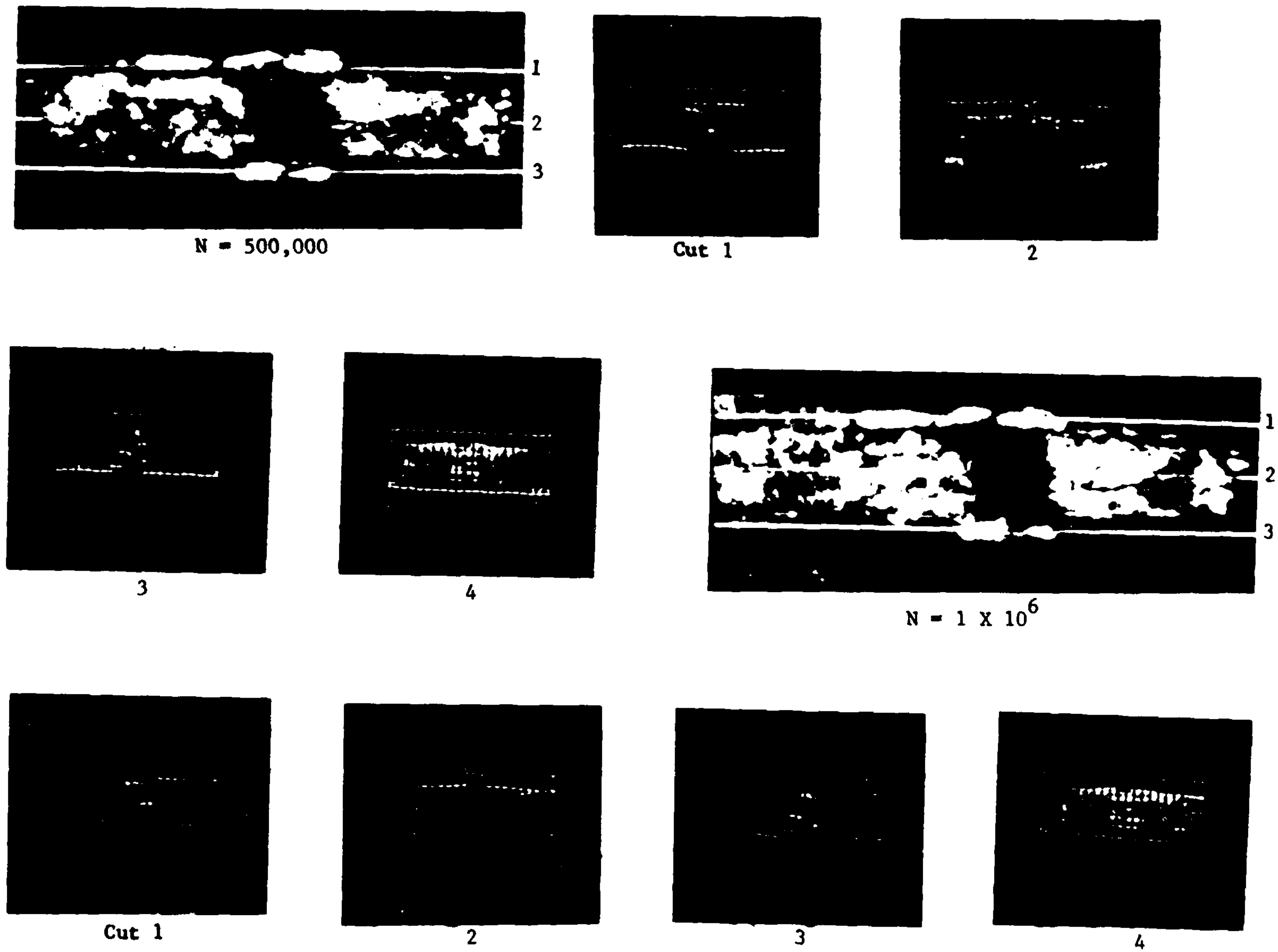
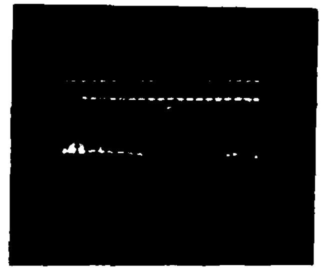
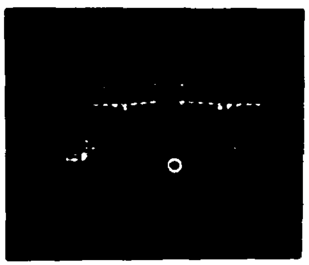


Figure D6d: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, R = -0.3 (AB-11, 12 x 10^6 without failure)

N = 2 X 10^6

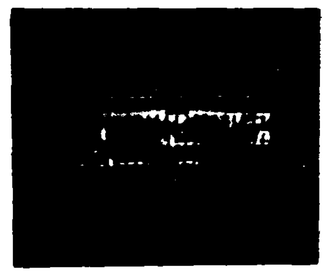


Cut 1



2

3



4

Figure D6e: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, R = -0.3 (AB-11, 12 x 10^6 without failure)

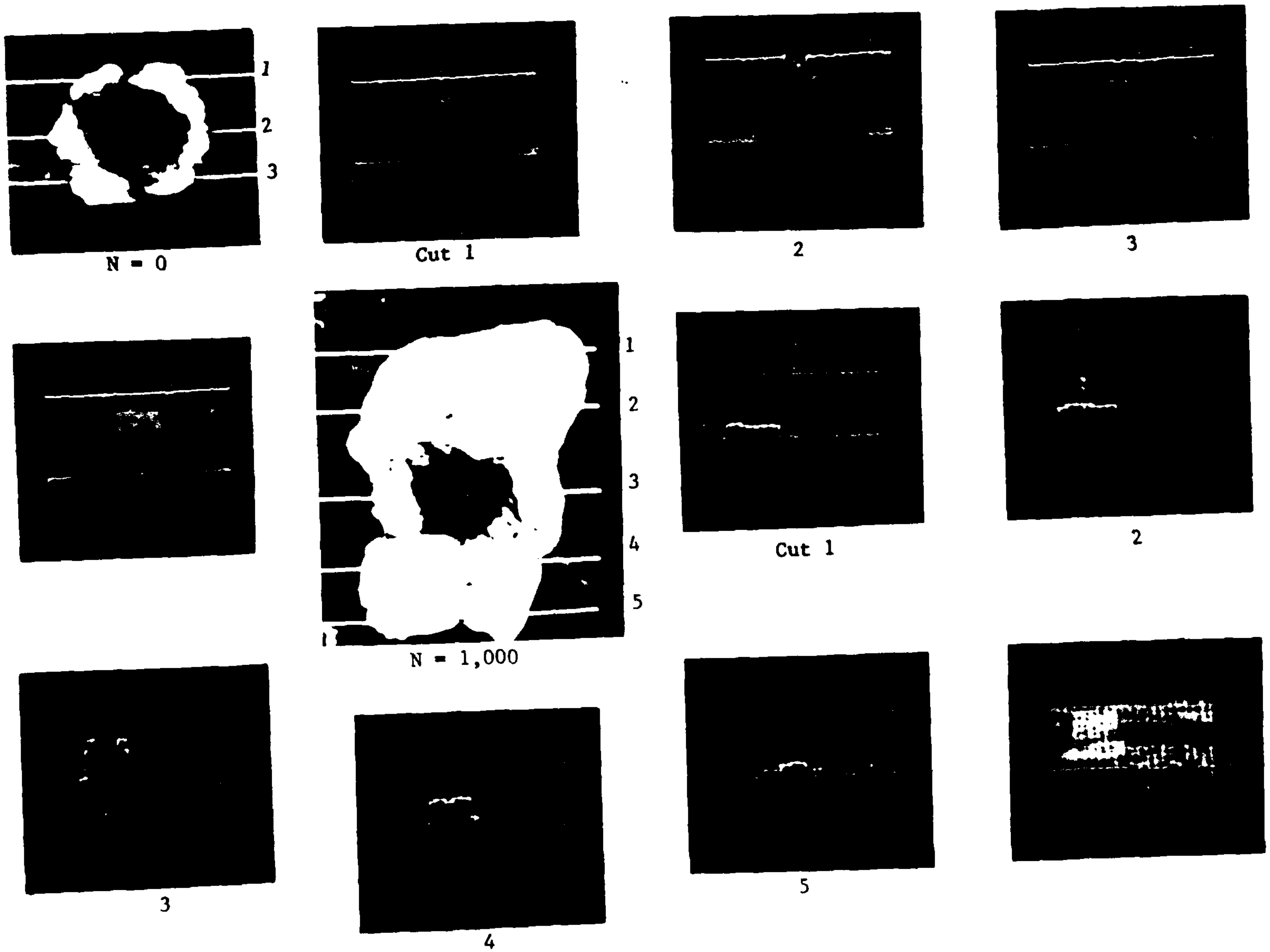


Figure D7: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) BBC-12, N_f = 2,460)

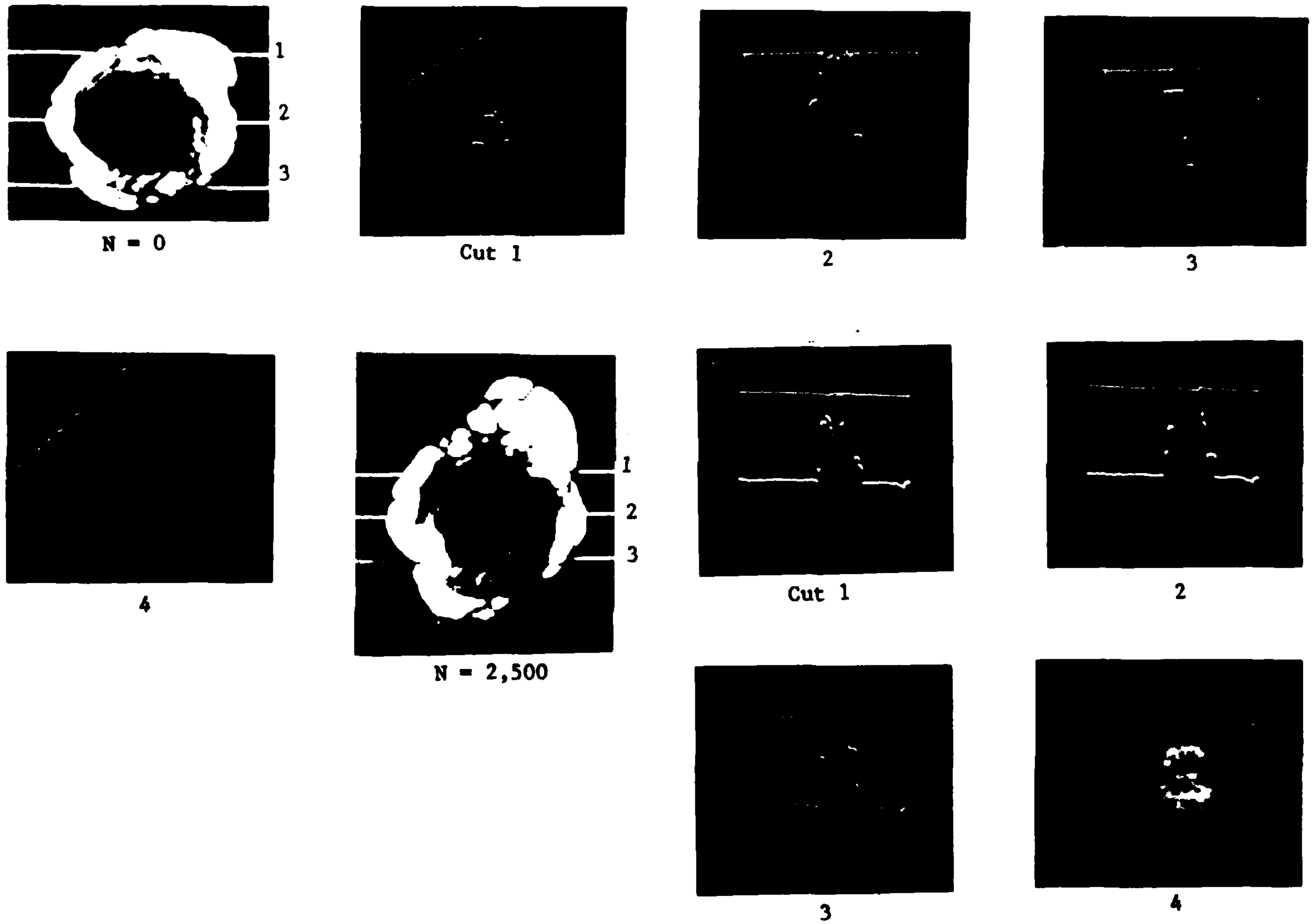


Figure D8a: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, N_f = 58,005)

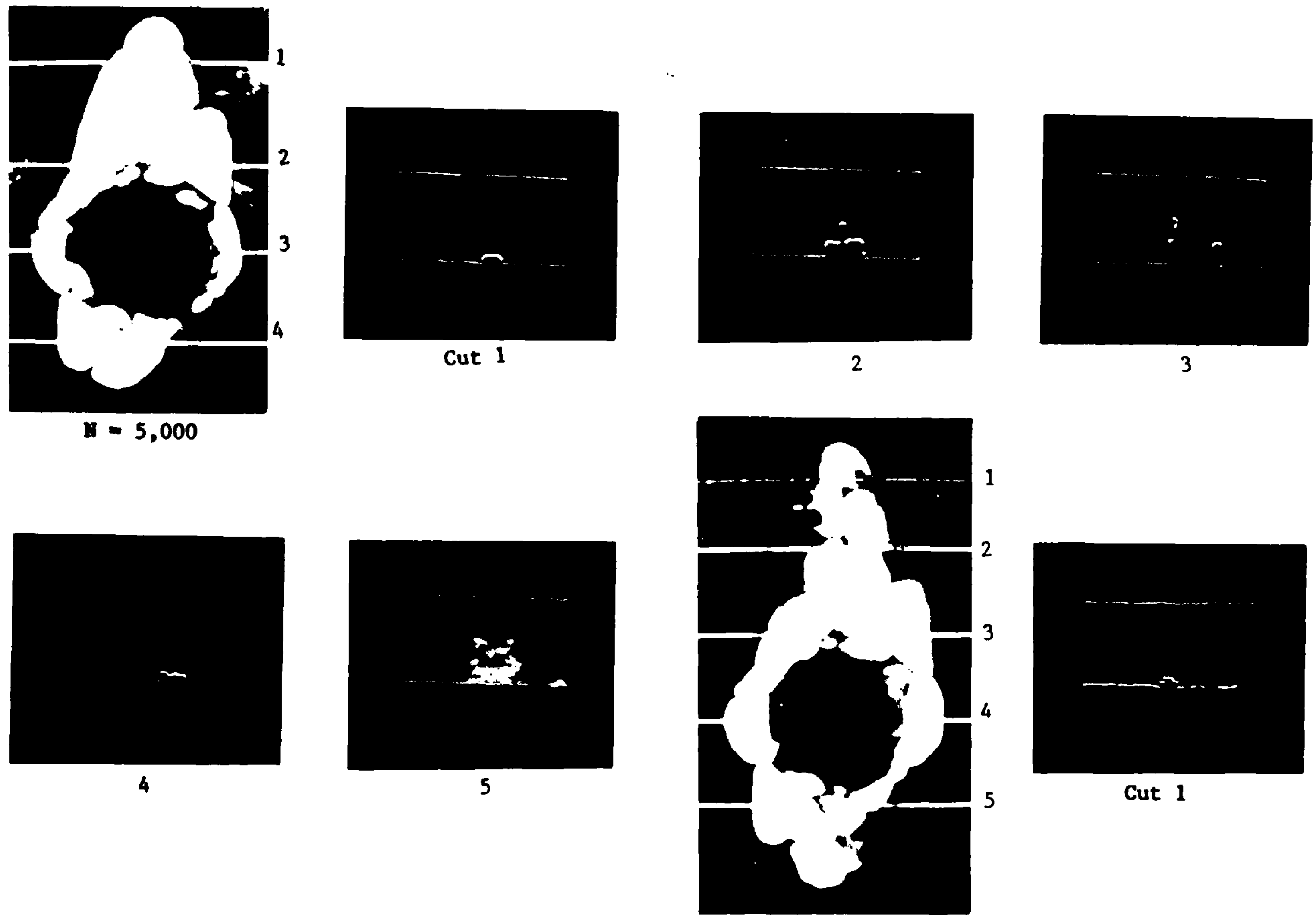


Figure D8b: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, N_f = 58,005)

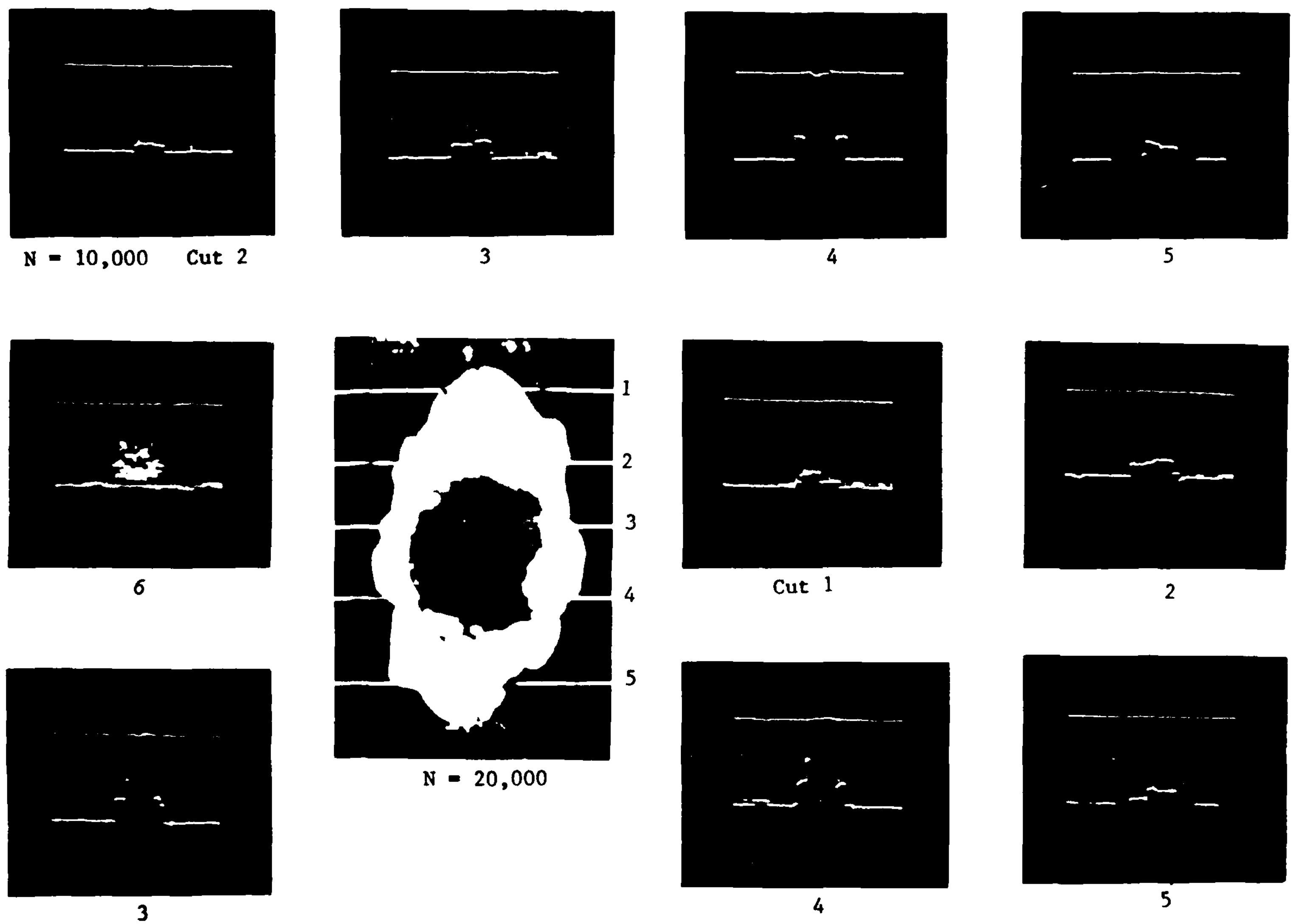


Figure D8c: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, N_f = 58,005)

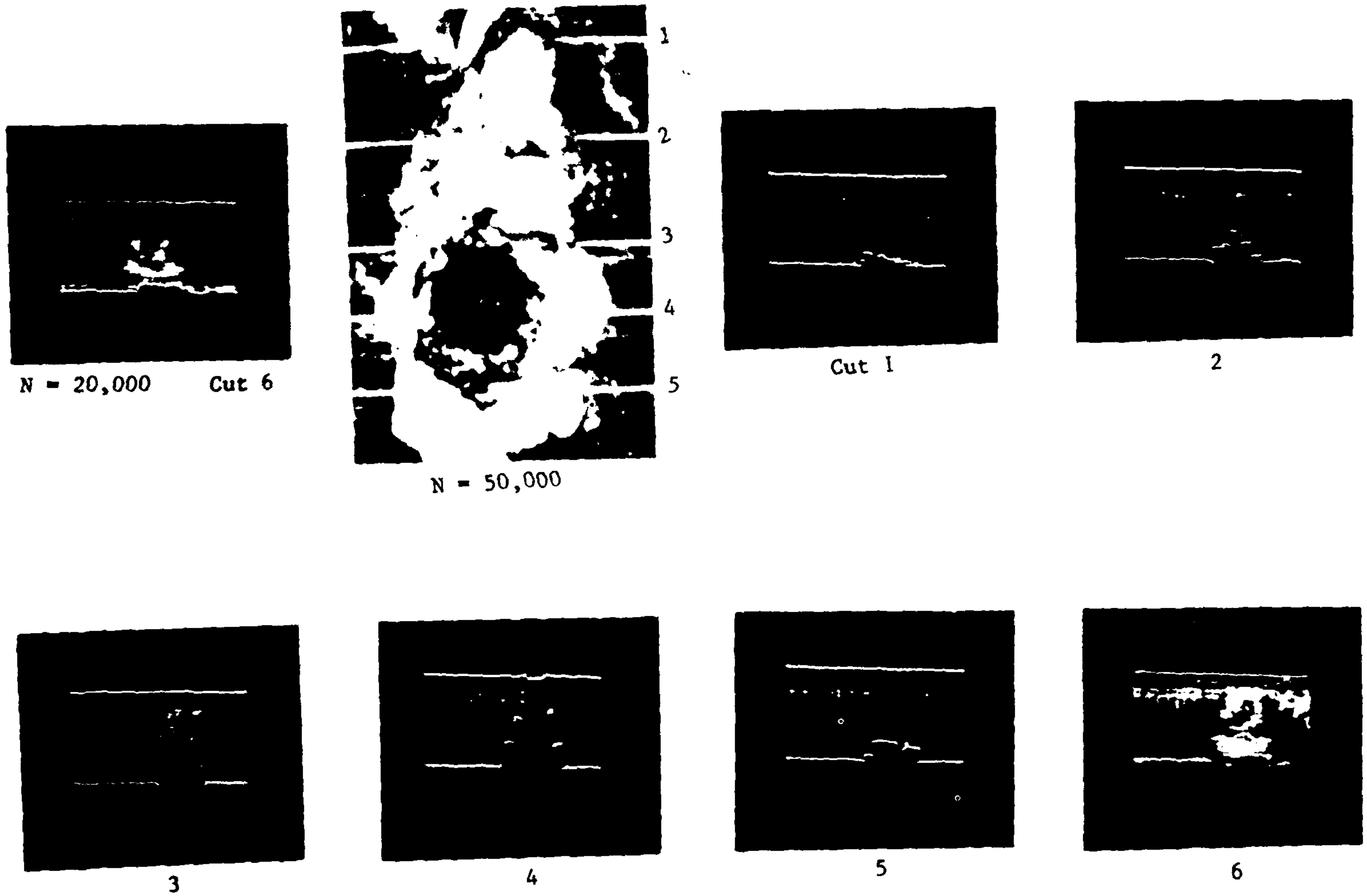


Figure D8d: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, N_f = 58,005)

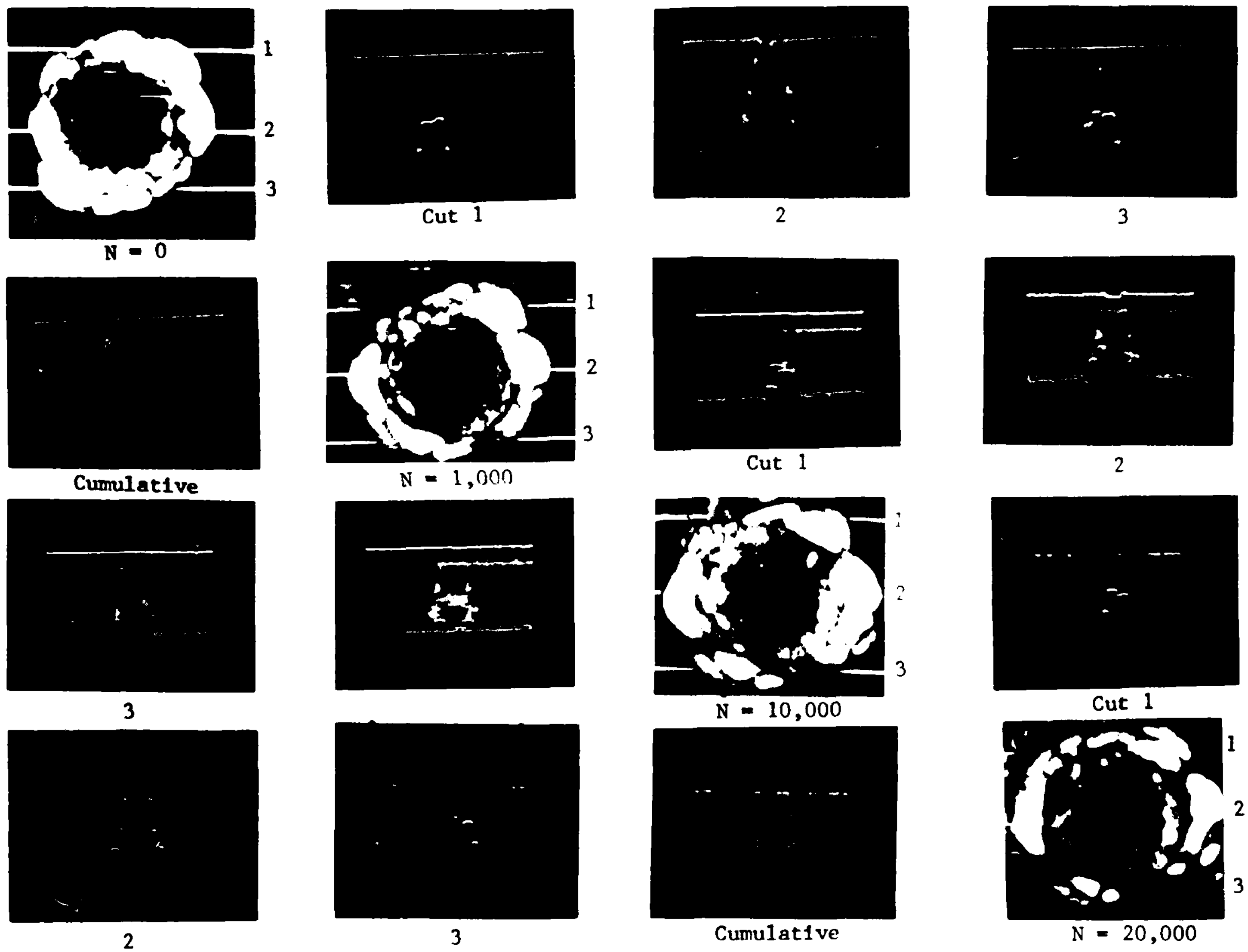


Figure D9a: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, R = -0.3 (EA-8, 12 x 10^6 without failure)

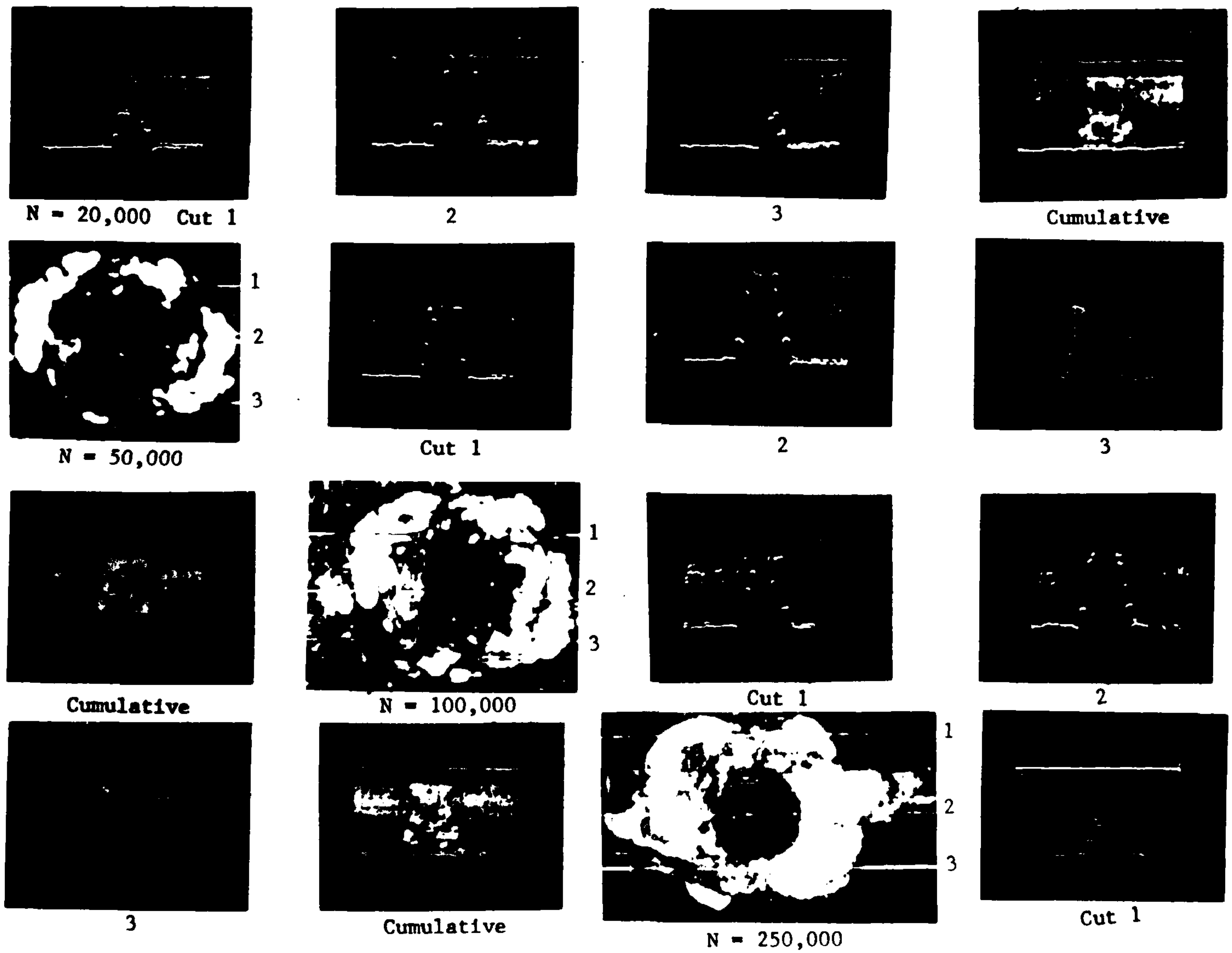


Figure D9b: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, R = -0.3 (EA-8, 12×10^6 without failure)

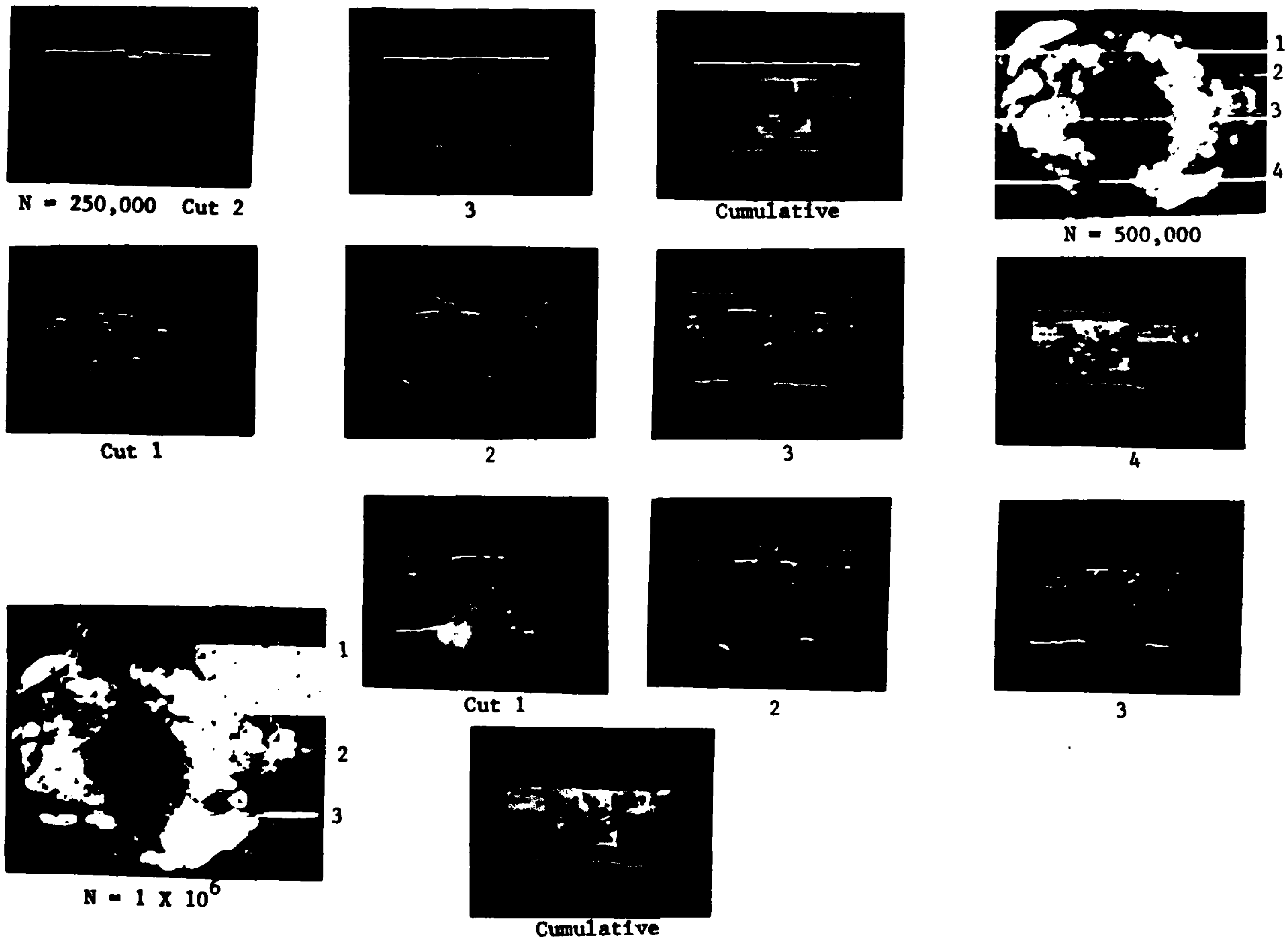


Figure D9c: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, R = -0.3 (EA-8, 12 x 10^6 without failure)

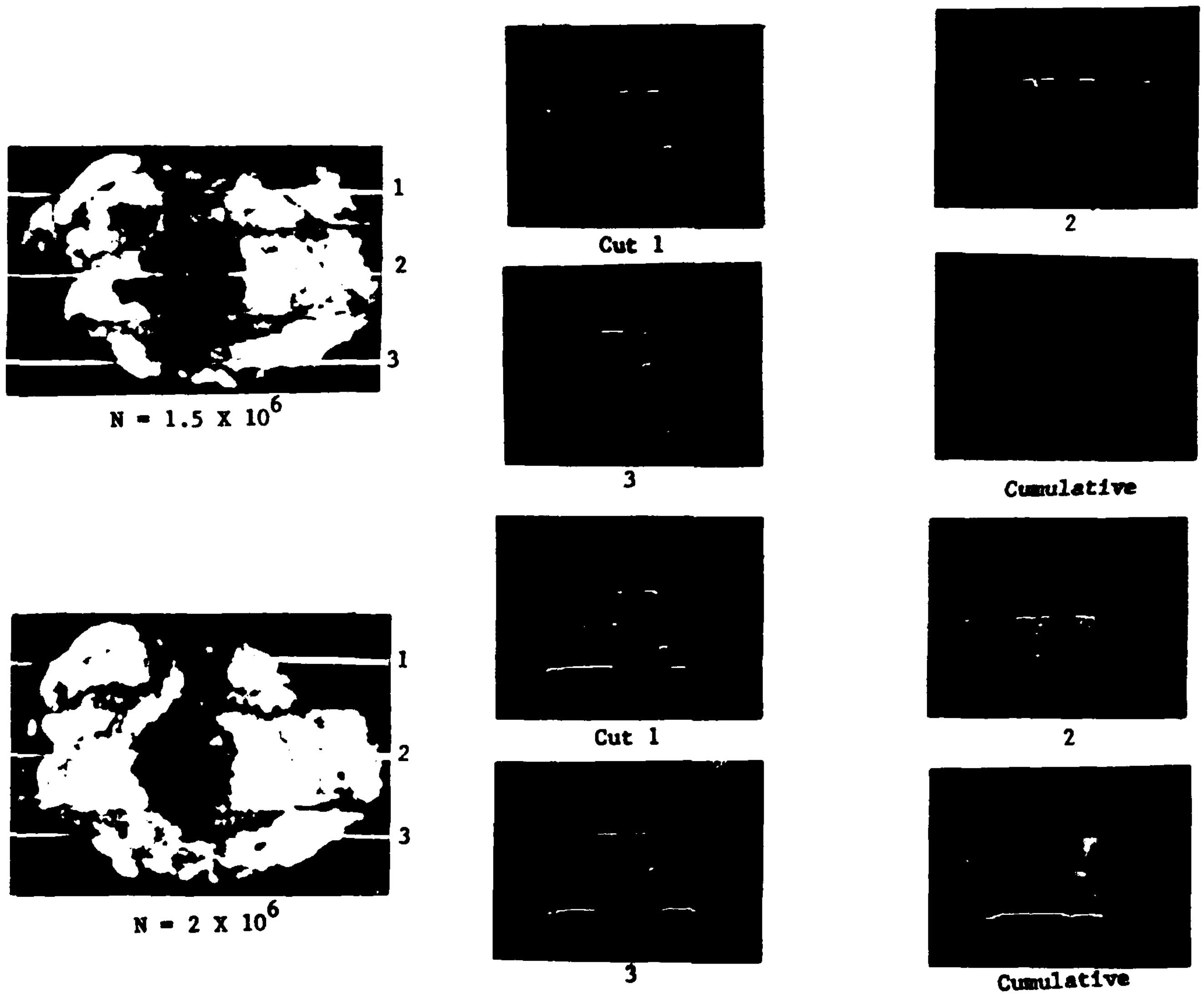


Figure D9d: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, $R = -0.3$ (EA-8, 12×10^6 without failure)

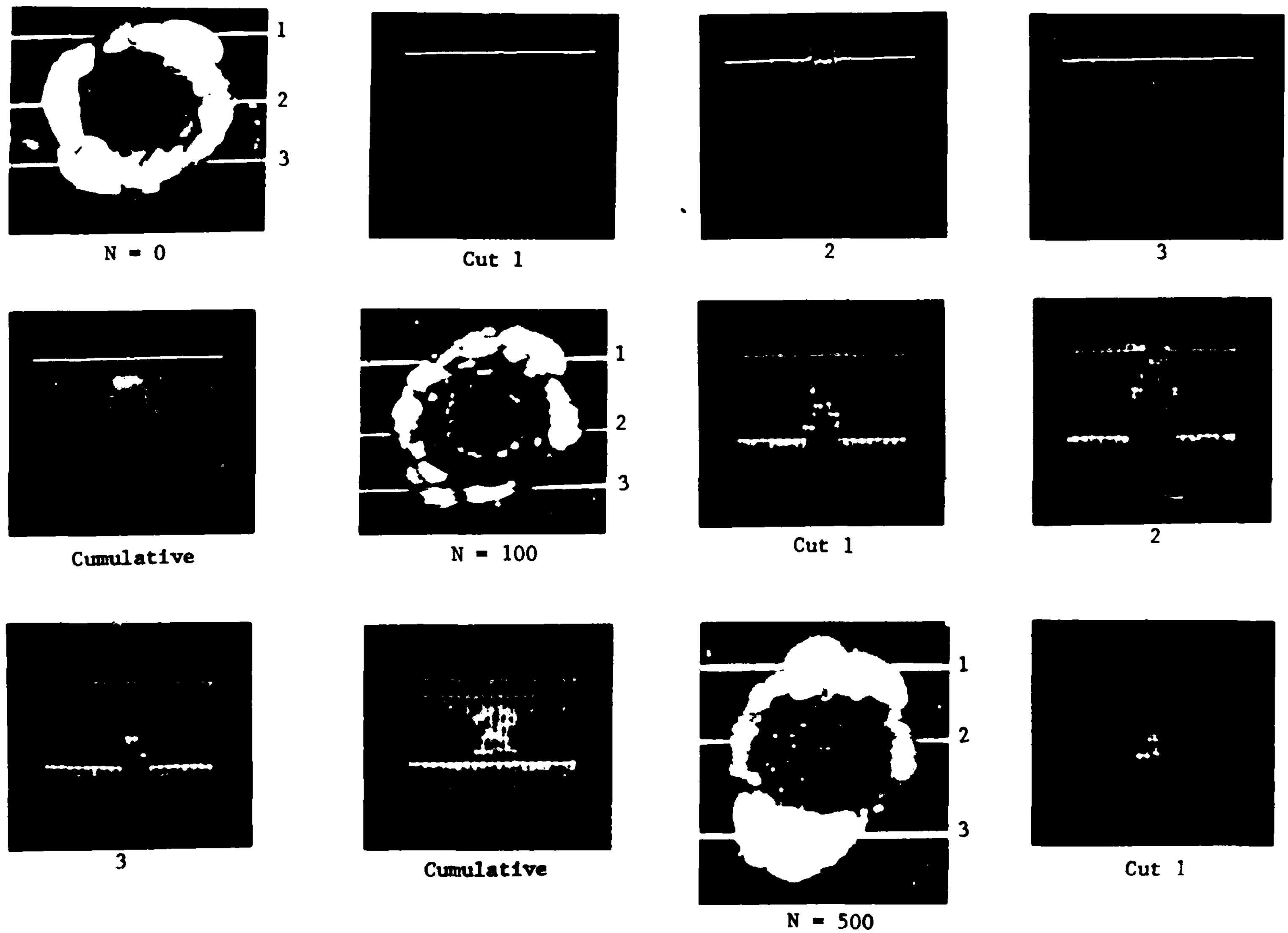


Figure D10a: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, N_f = 72,420)

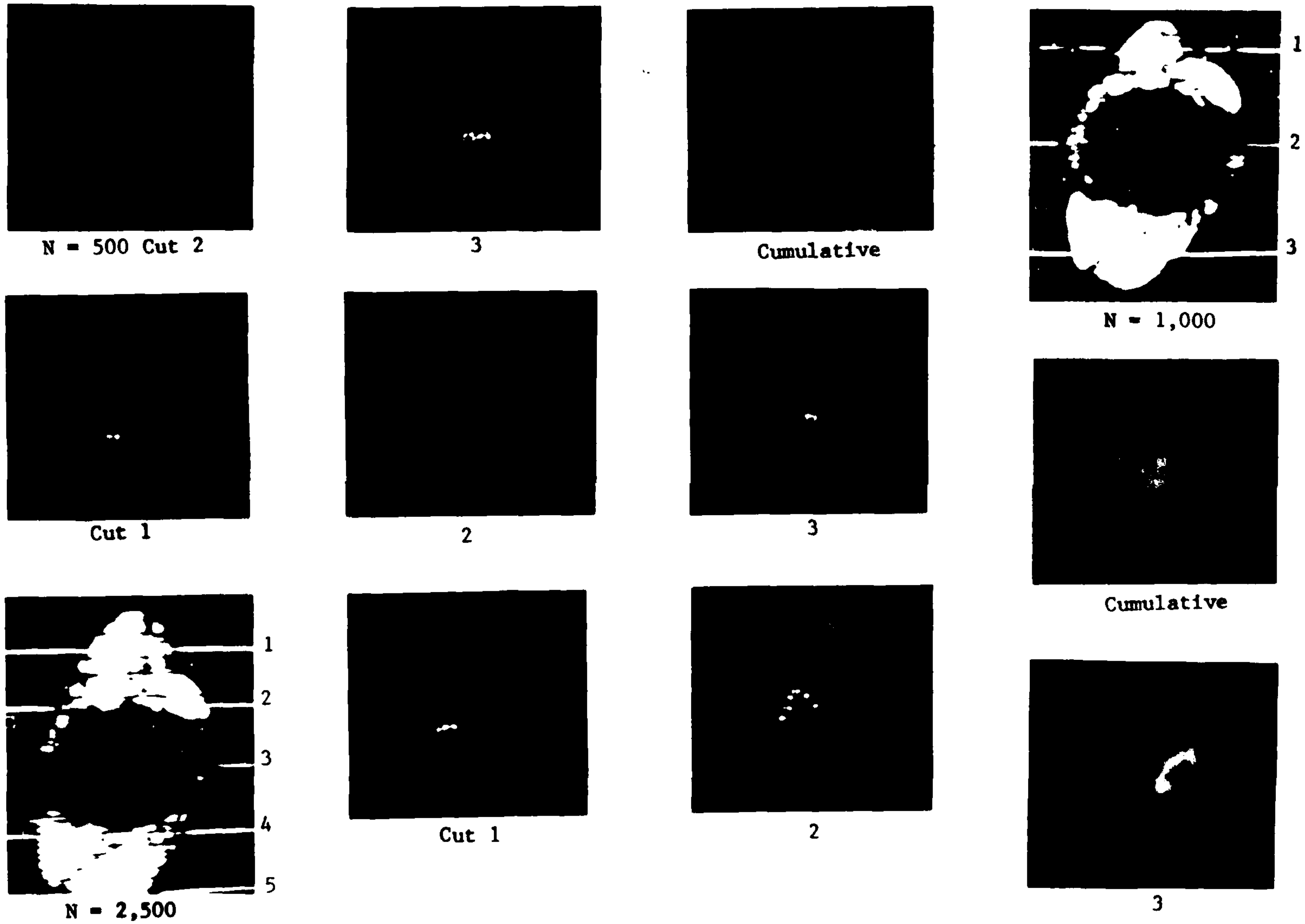


Figure D10b: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, N_f = 72,420)

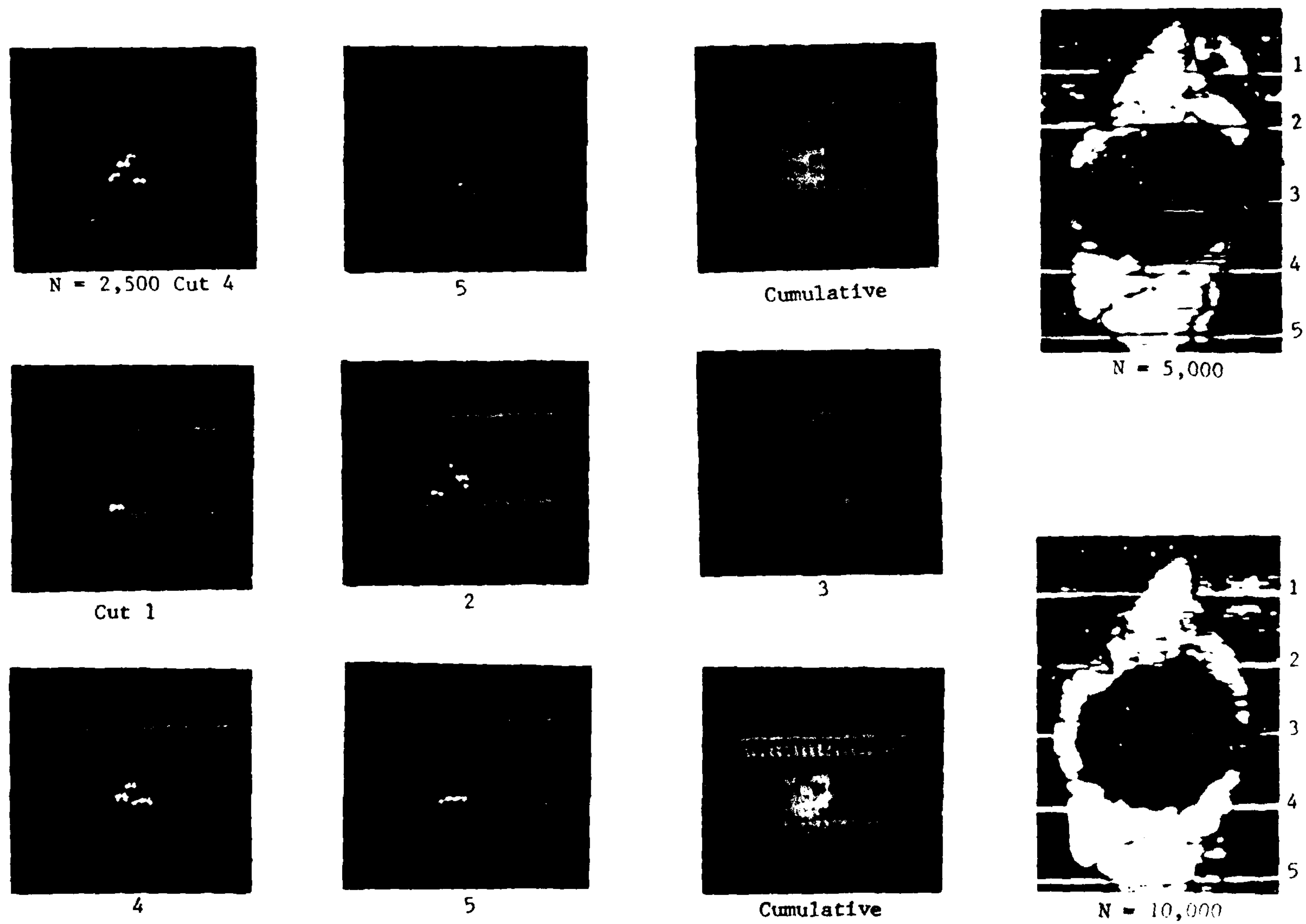


Figure D10c: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, N_f = 72,420)

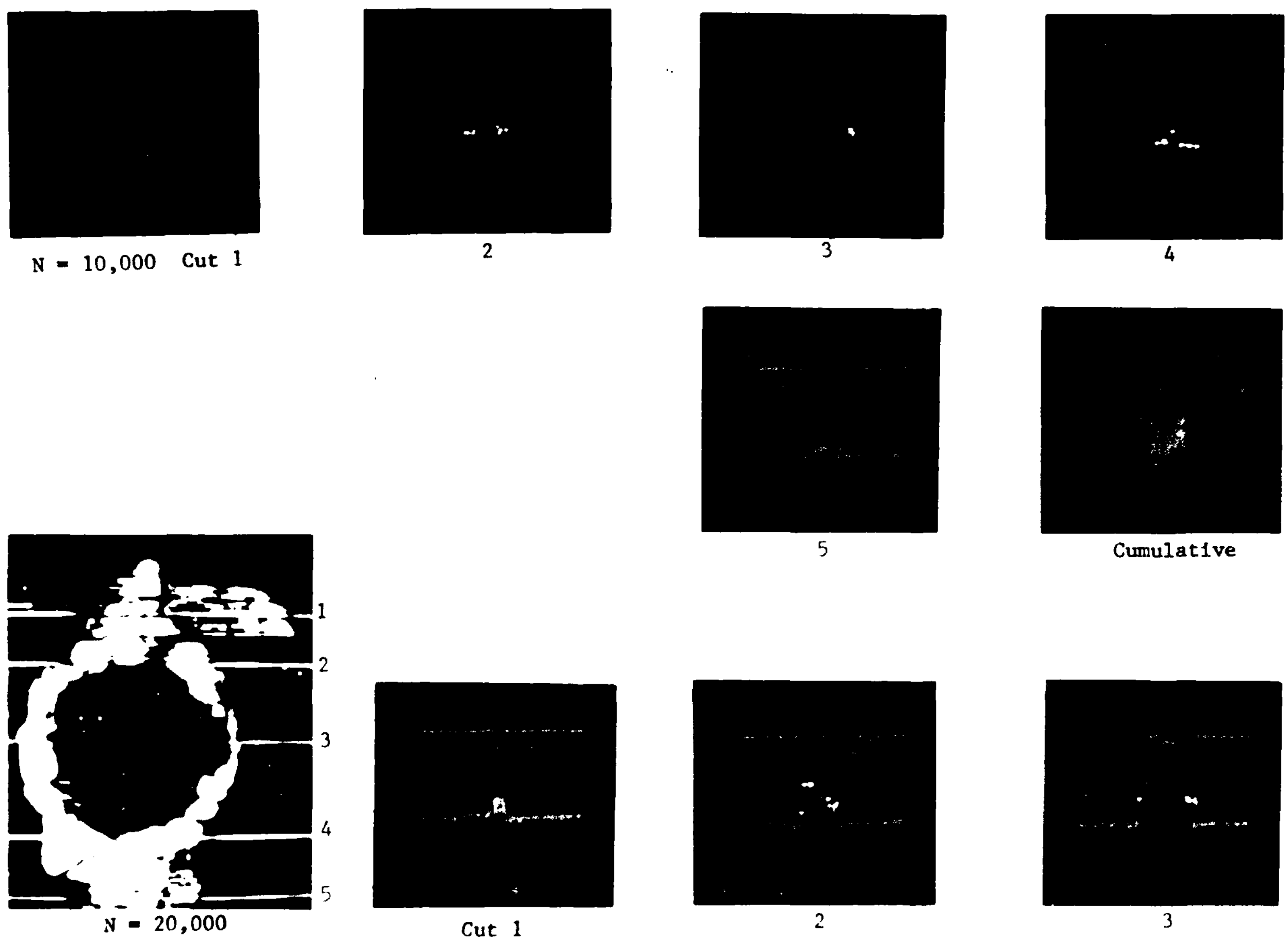


Figure D10d: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, N_f = 72,420)

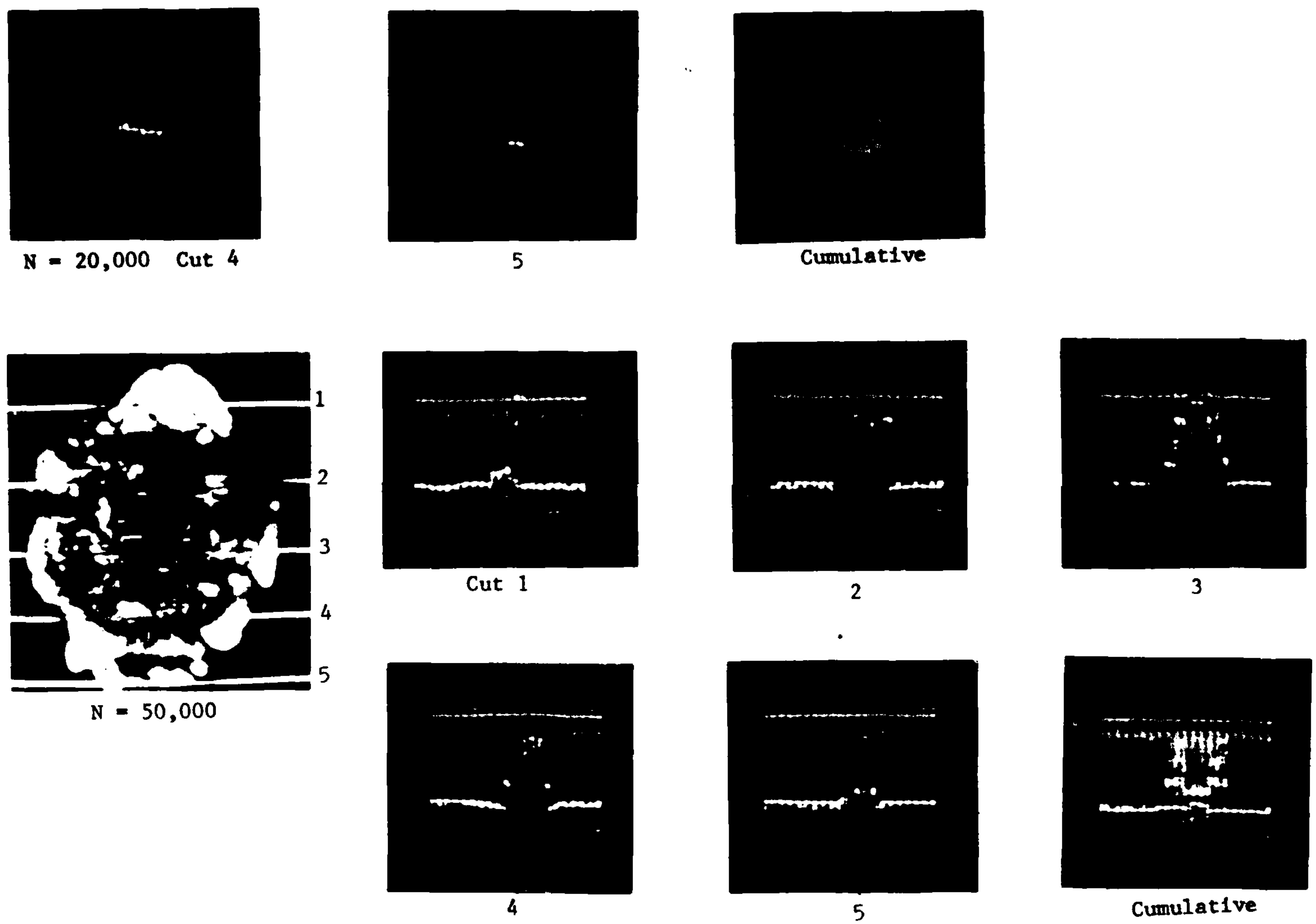


Figure D10e: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, N_f = 72,420)

APPENDIX E

Damage Characteristics of Specimens Tested for Residual Strength

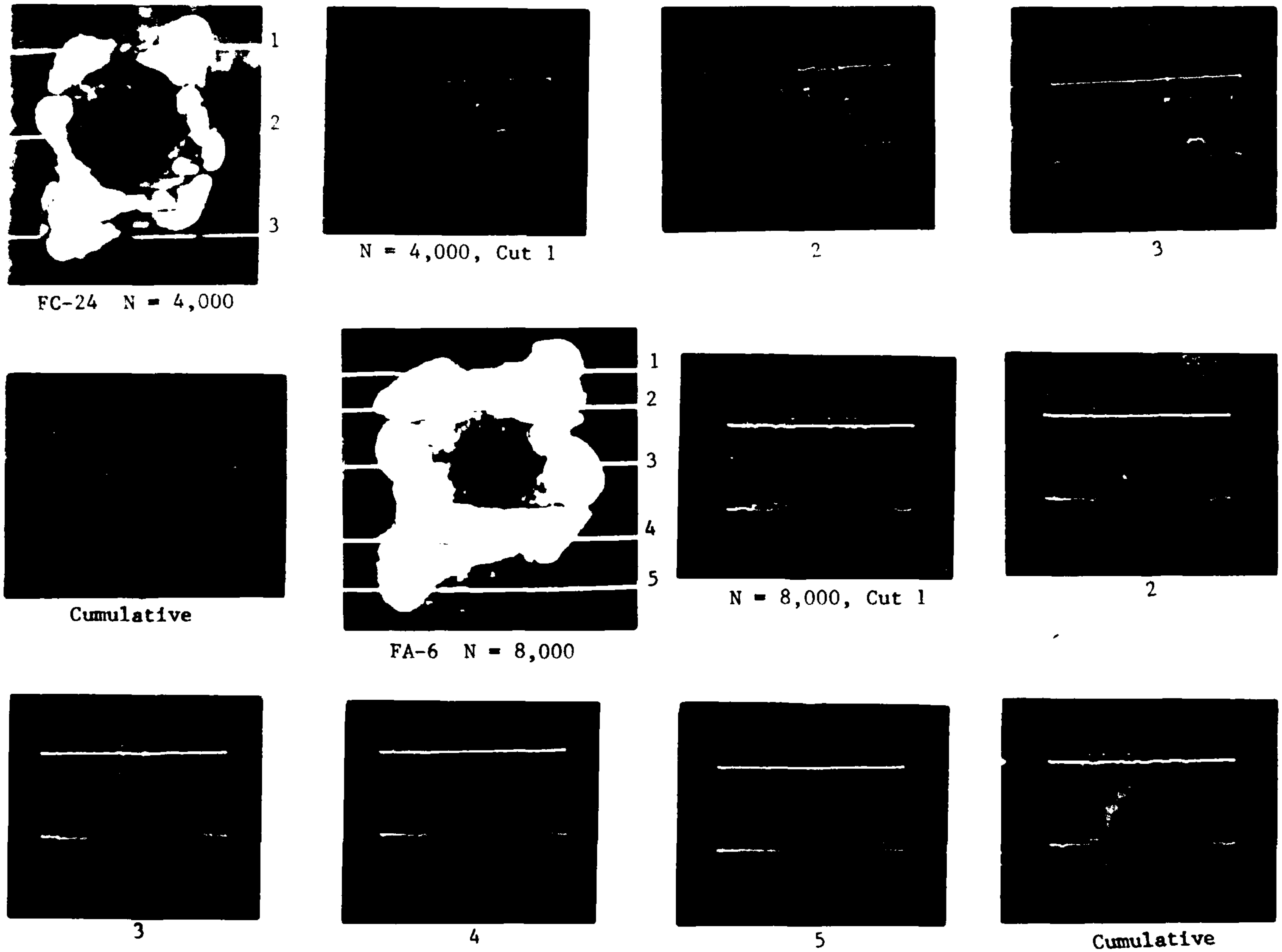


Figure E1a: Damage Characteristics of 24-Ply Specimens Fatigue Cycled at ± 35 ksi (± 241 MPa) for Residual Strength Determination

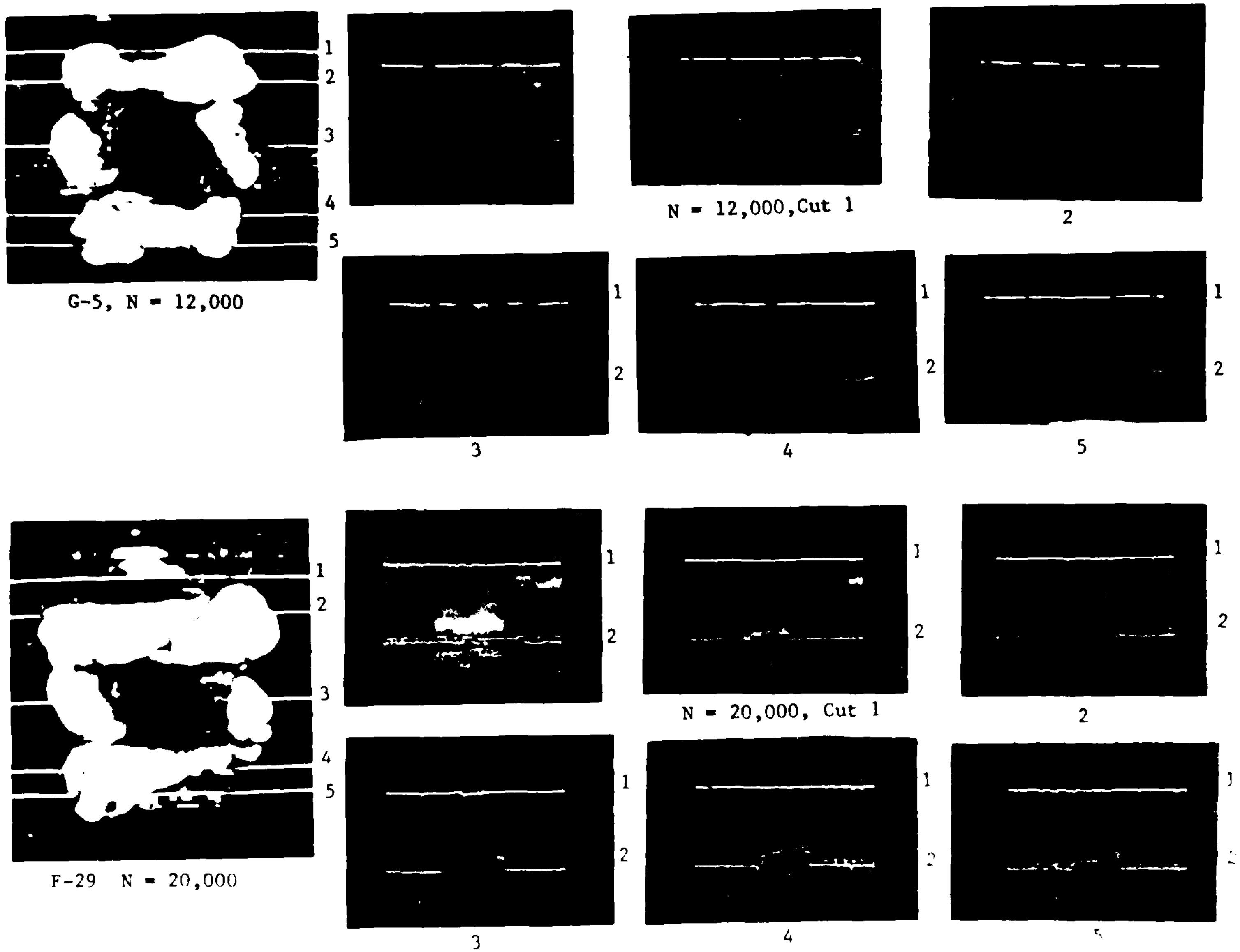


Figure E1b: Damage Characteristics of 24-Ply Specimens Fatigue Cycled at ± 35 ksi (+ 241 MPa) for Residual Strength Determination

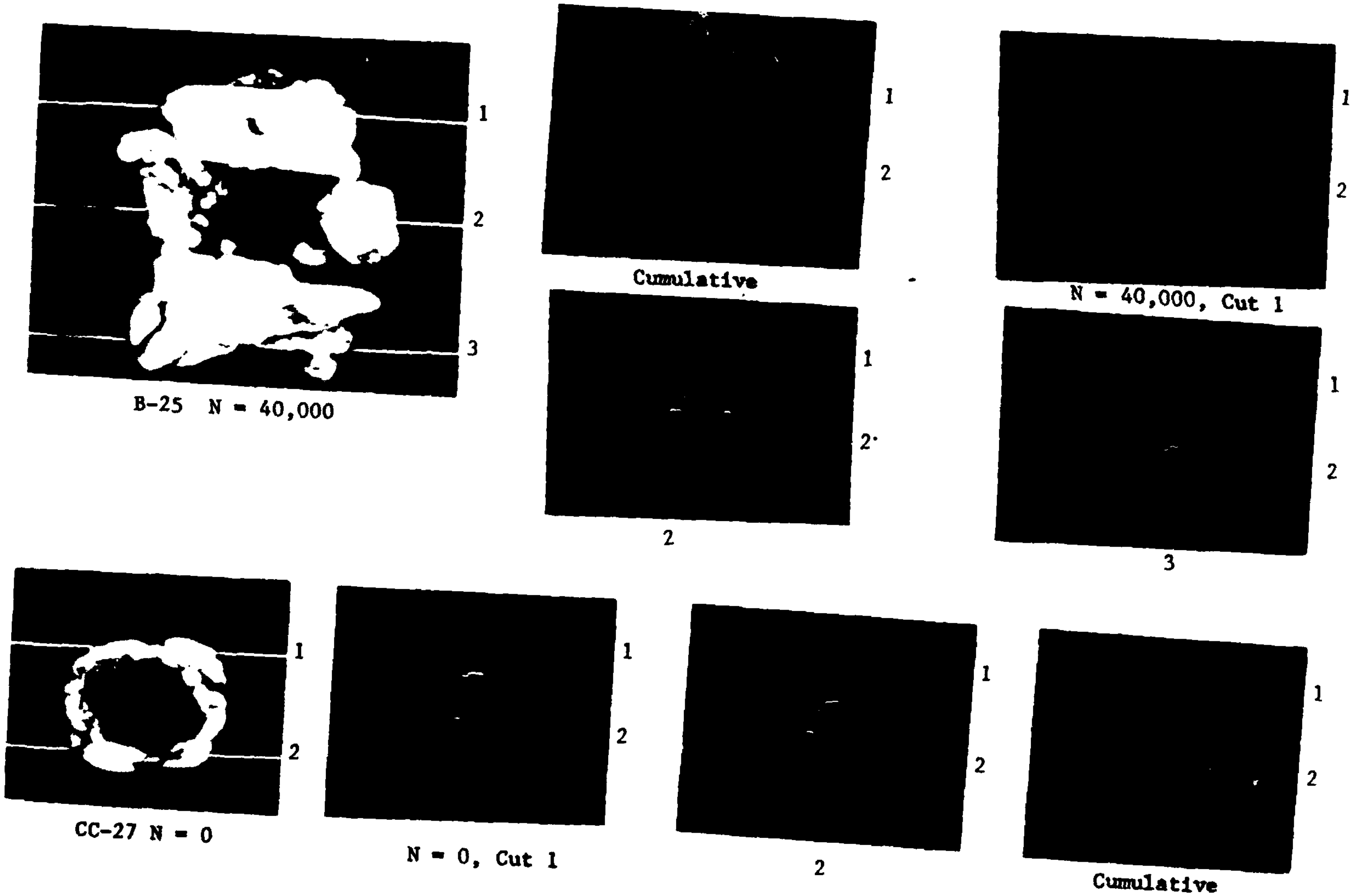


Figure E1c: Damage Characteristics of 24-Ply Specimens Fatigue Cycled at ± 35 ksi (± 241 MPa) for Residual Strength Determination

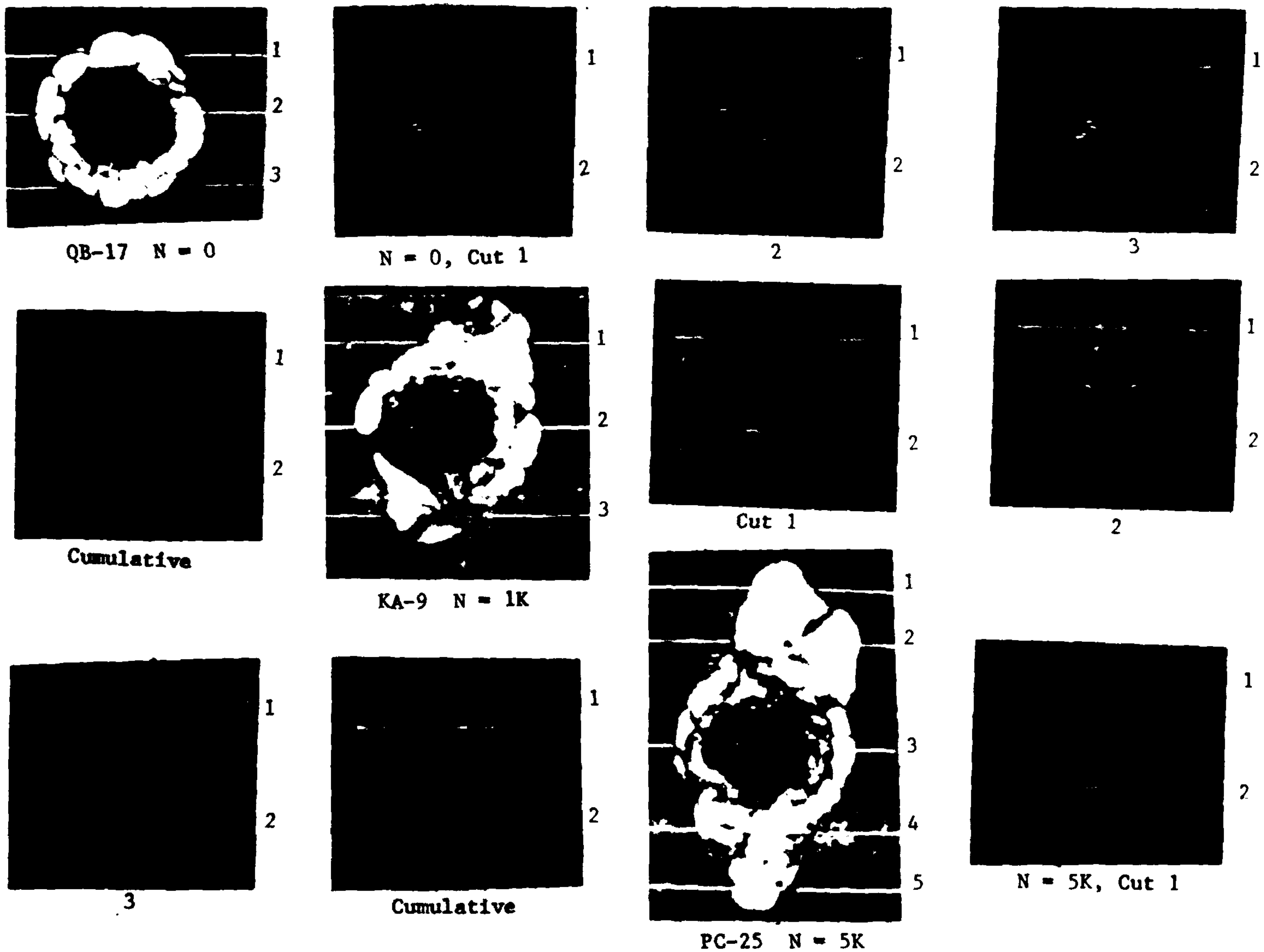


Figure E2a: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at $\pm$ 22 ksi (152 MPa) for Residual Strength Determination

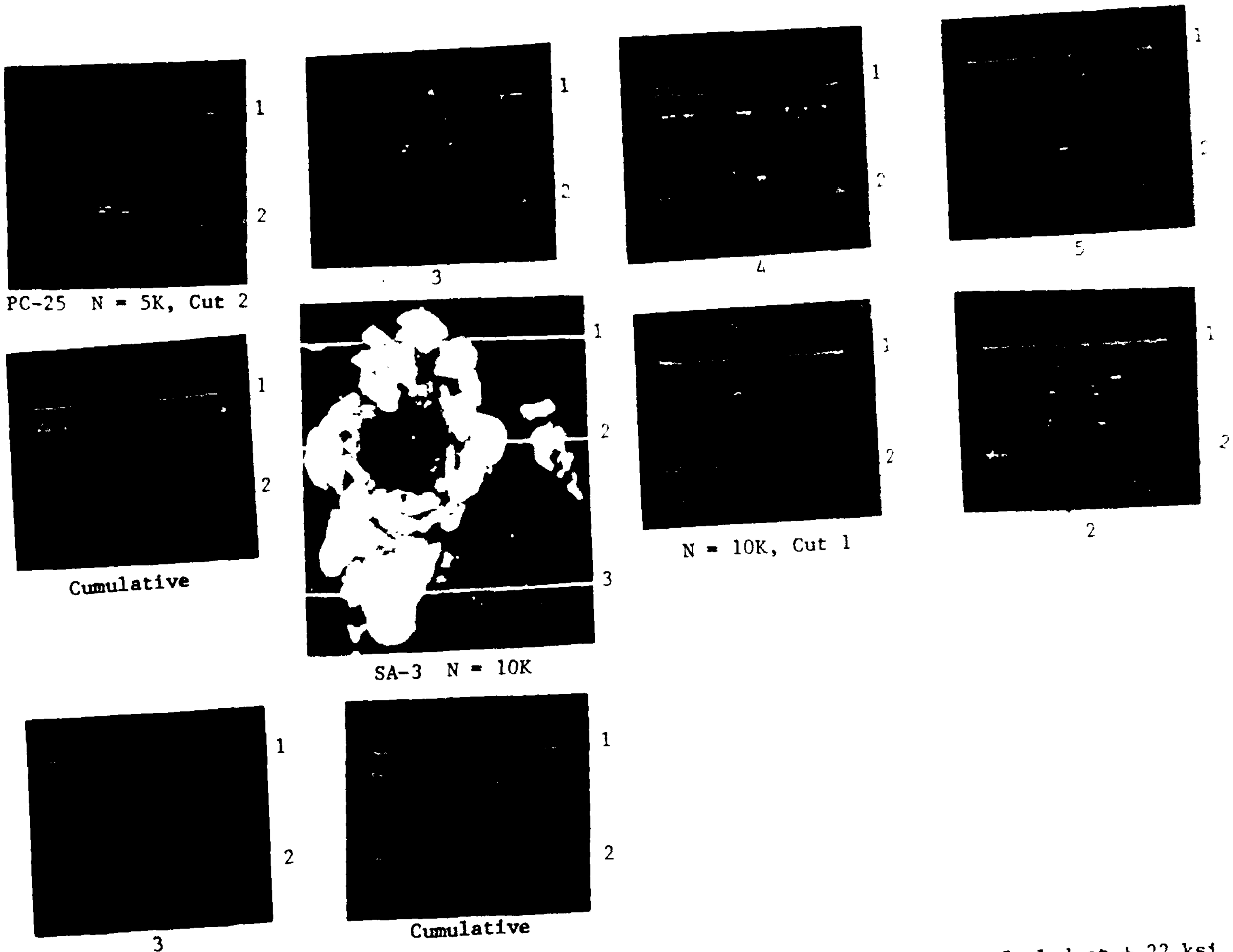


Figure E2b: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at $\pm$ 22 ksi ($\pm$152 MPa) for Residual Strength Determination

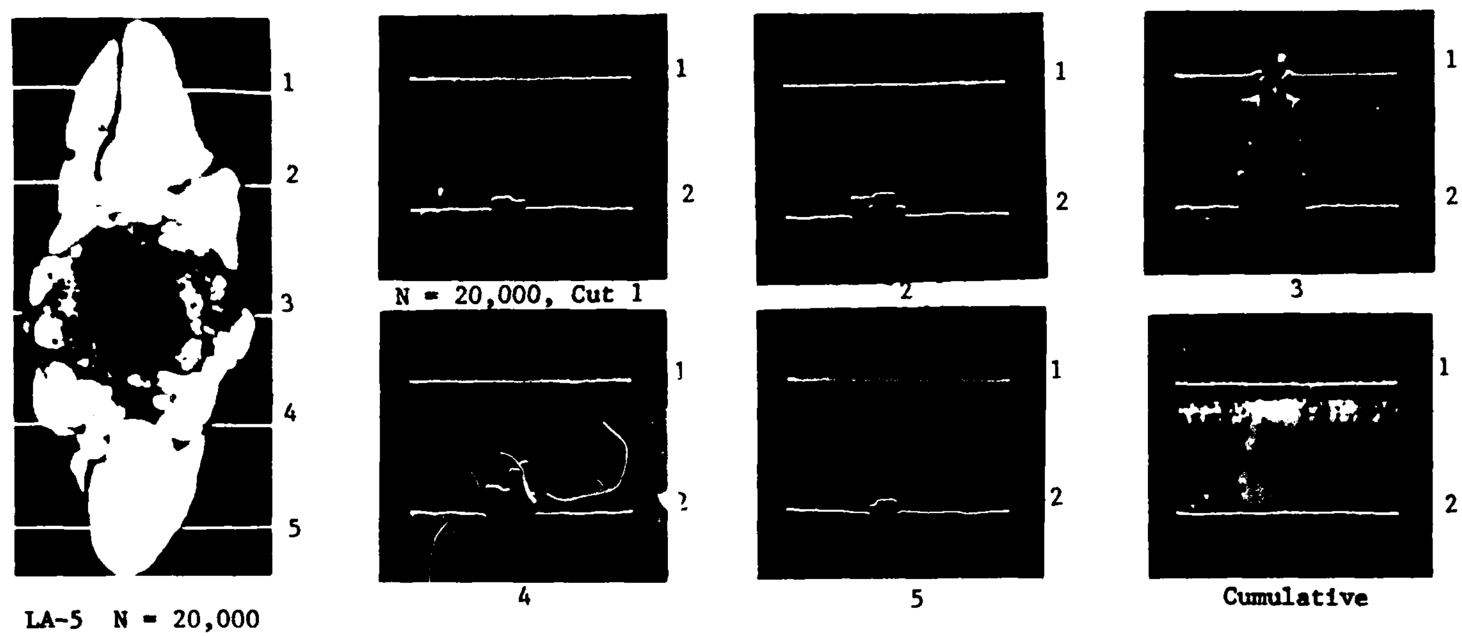


Figure E2c: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at $\pm$ 22 ksi ($\pm$152 MPa) for Residual Strength Determination

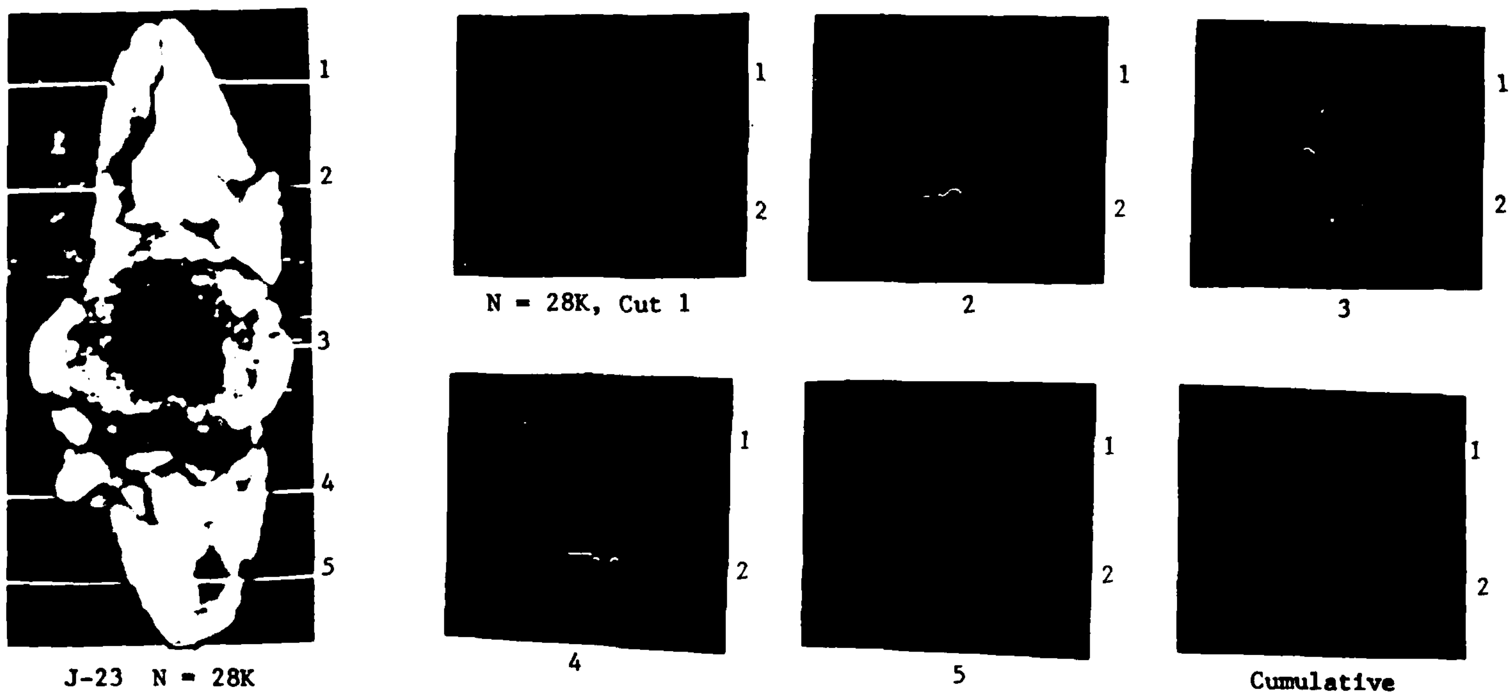


Figure E2d: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at $\pm$ 22 ksi ($\pm$152 MPa) for Residual Strength Determination

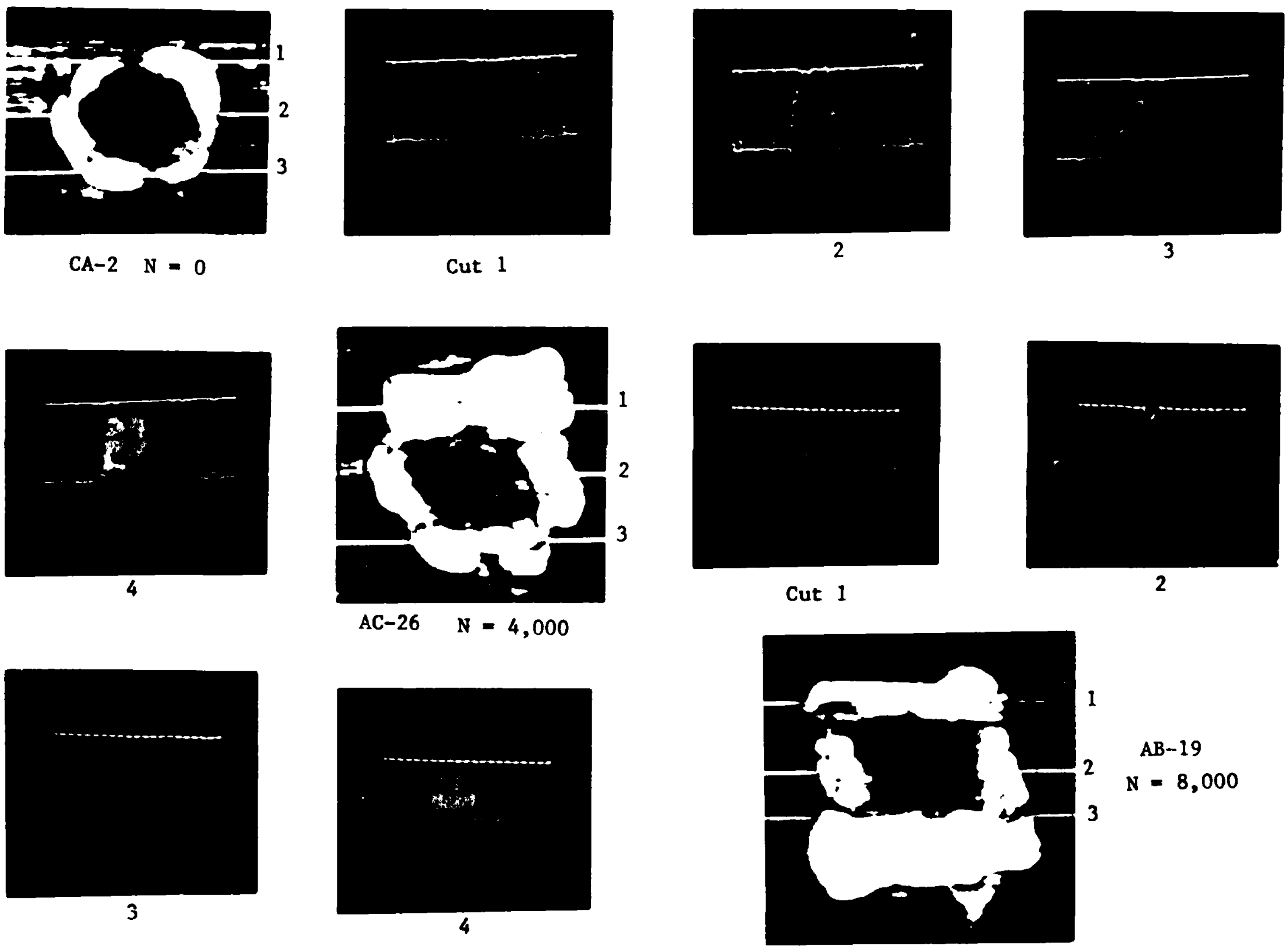


Figure E3a: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition A, 4-Bar Support (See Table XXXV, Vol. II)

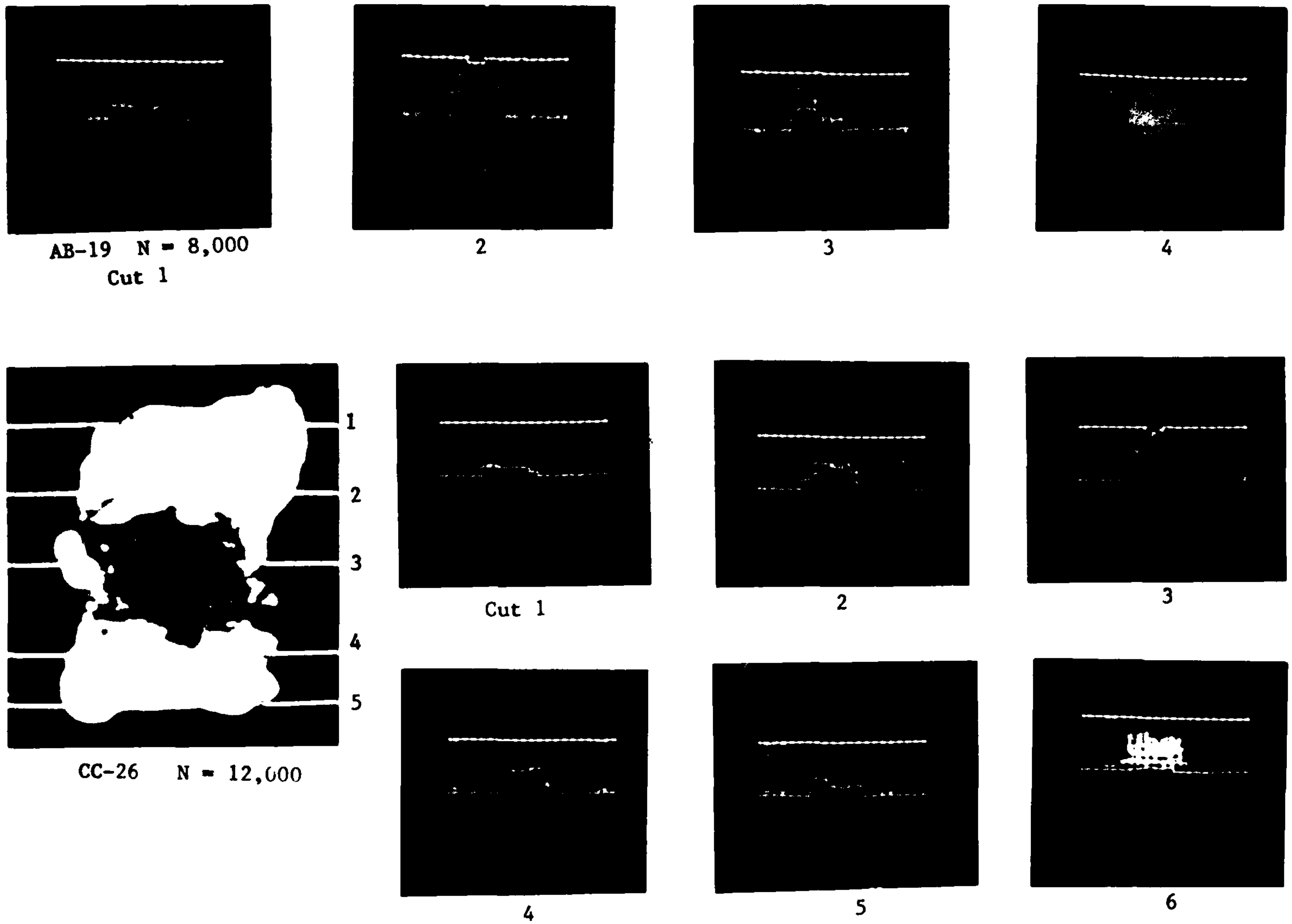


Figure E3b: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition A, 4-Bar Support (See Table XXXV, Vol. II)

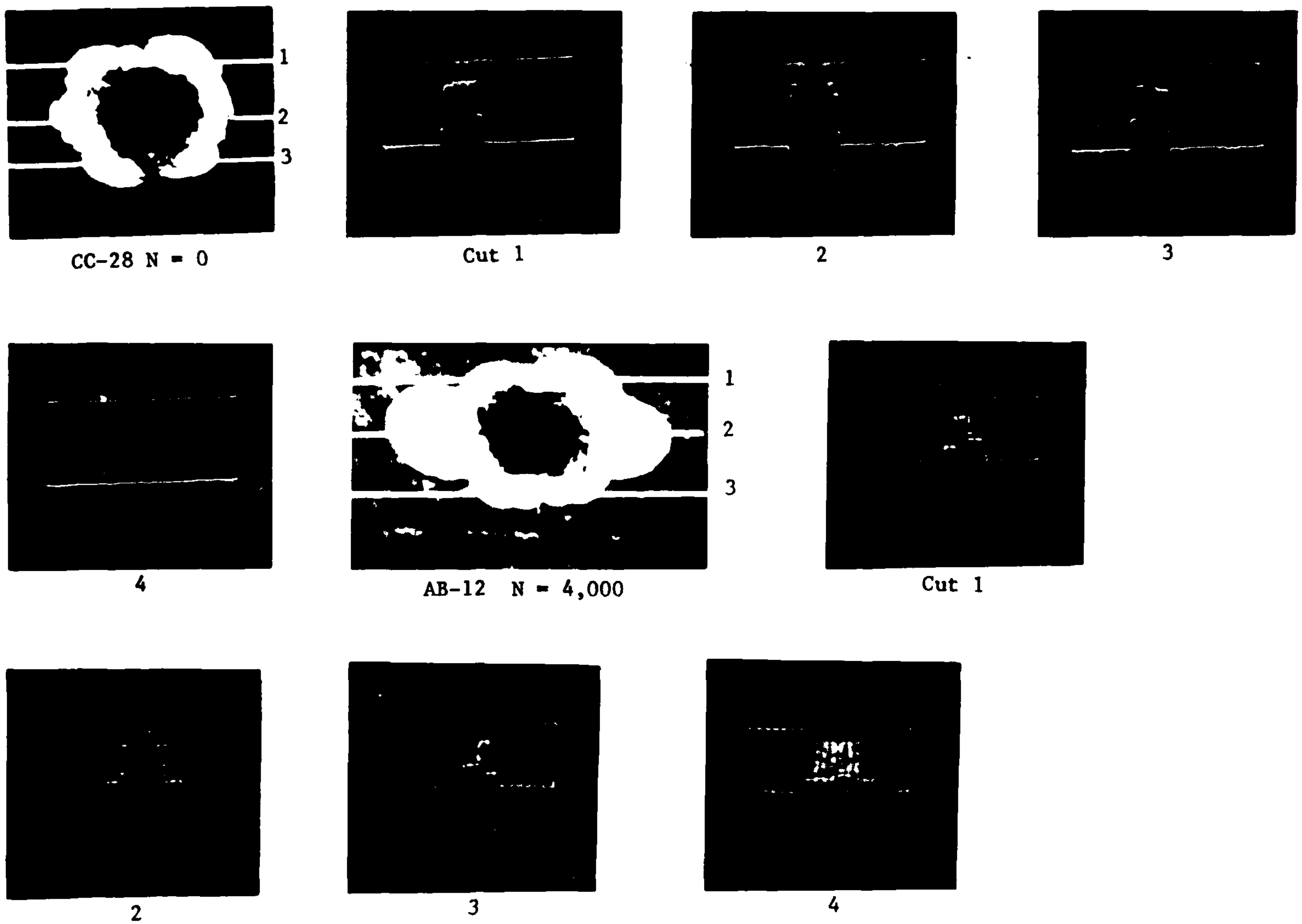


Figure E4a: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B, R = -0.3 (See Table XXXV, Vol. II)

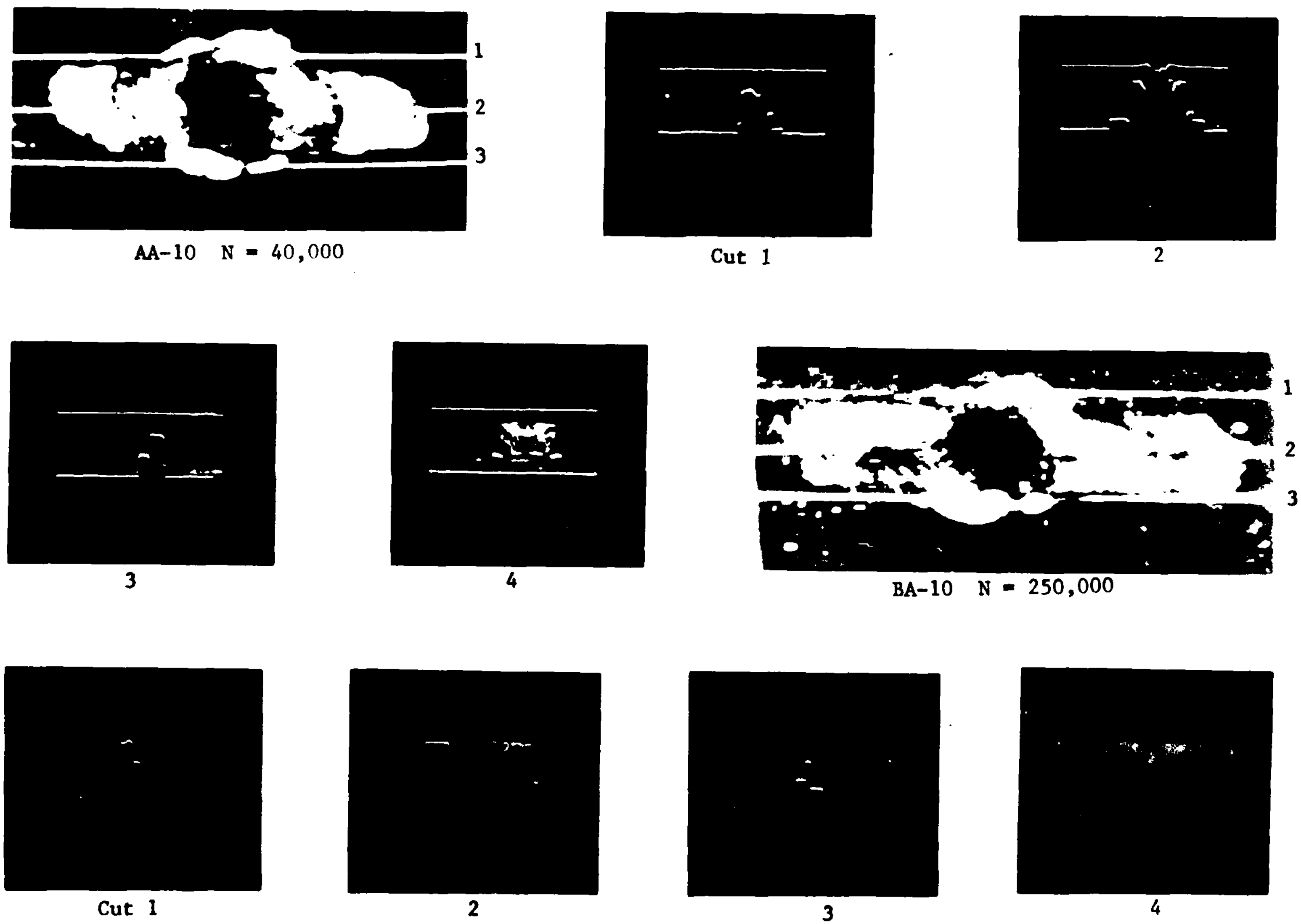


Figure E4b: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B, R = -0.3 (See Table XXXV, Vol. II)

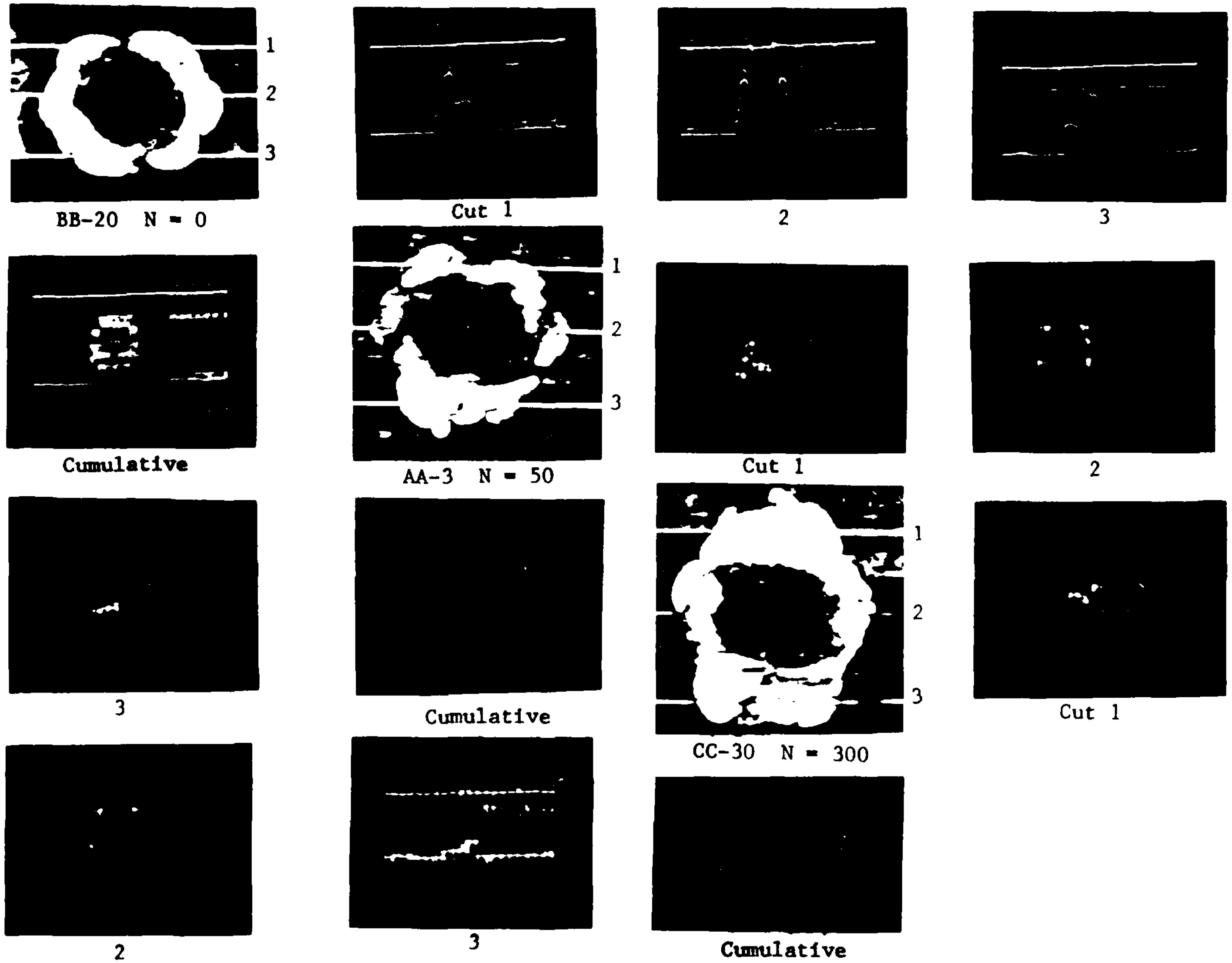


Figure E5a: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition C, 180°F (82°C) (See Table XXXV, Vol. II)

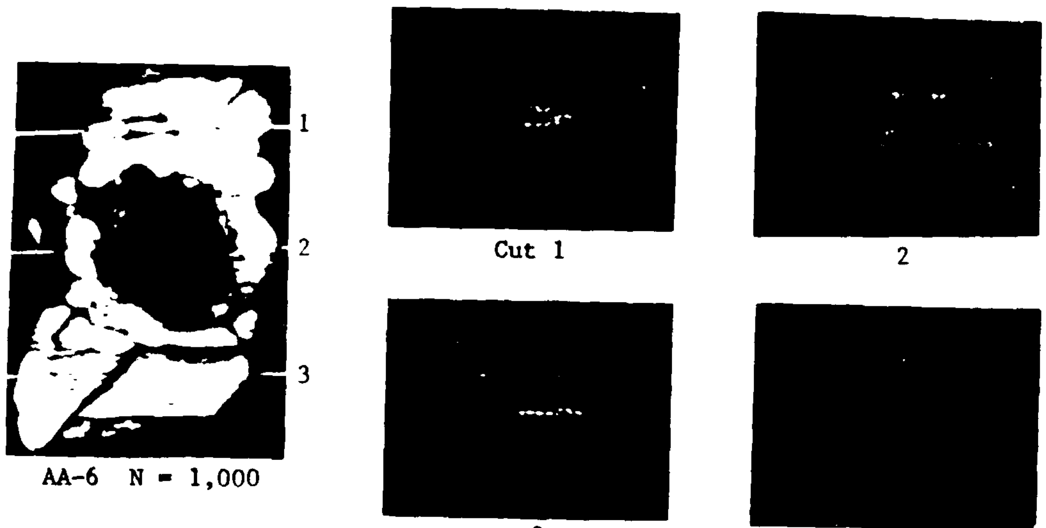


Figure E5b: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition C, 180°F (82°C) (See Table XXXV, Vol II)

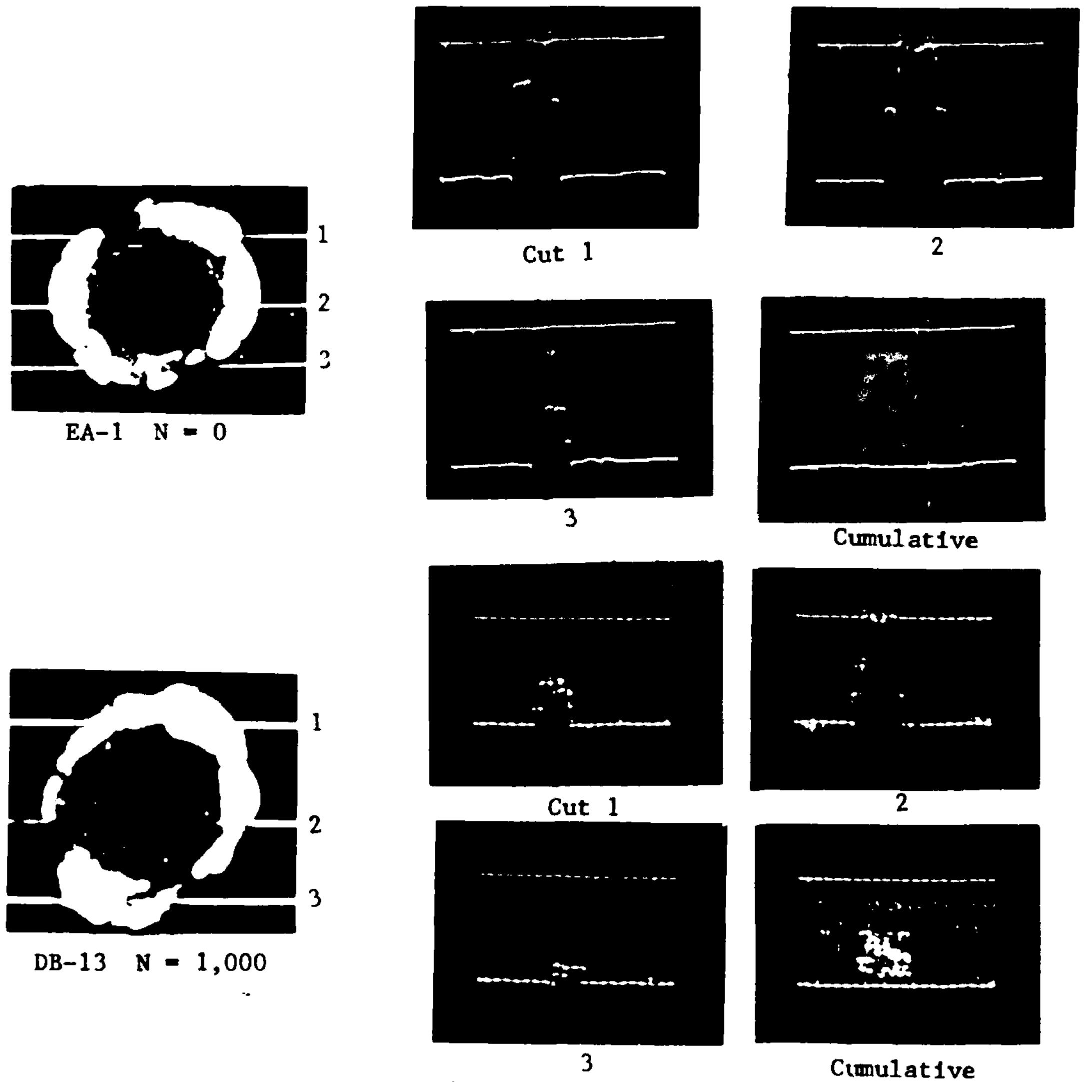


Figure E6a: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition A, 4-Bar Support (See Table XXXV, Vol. II)

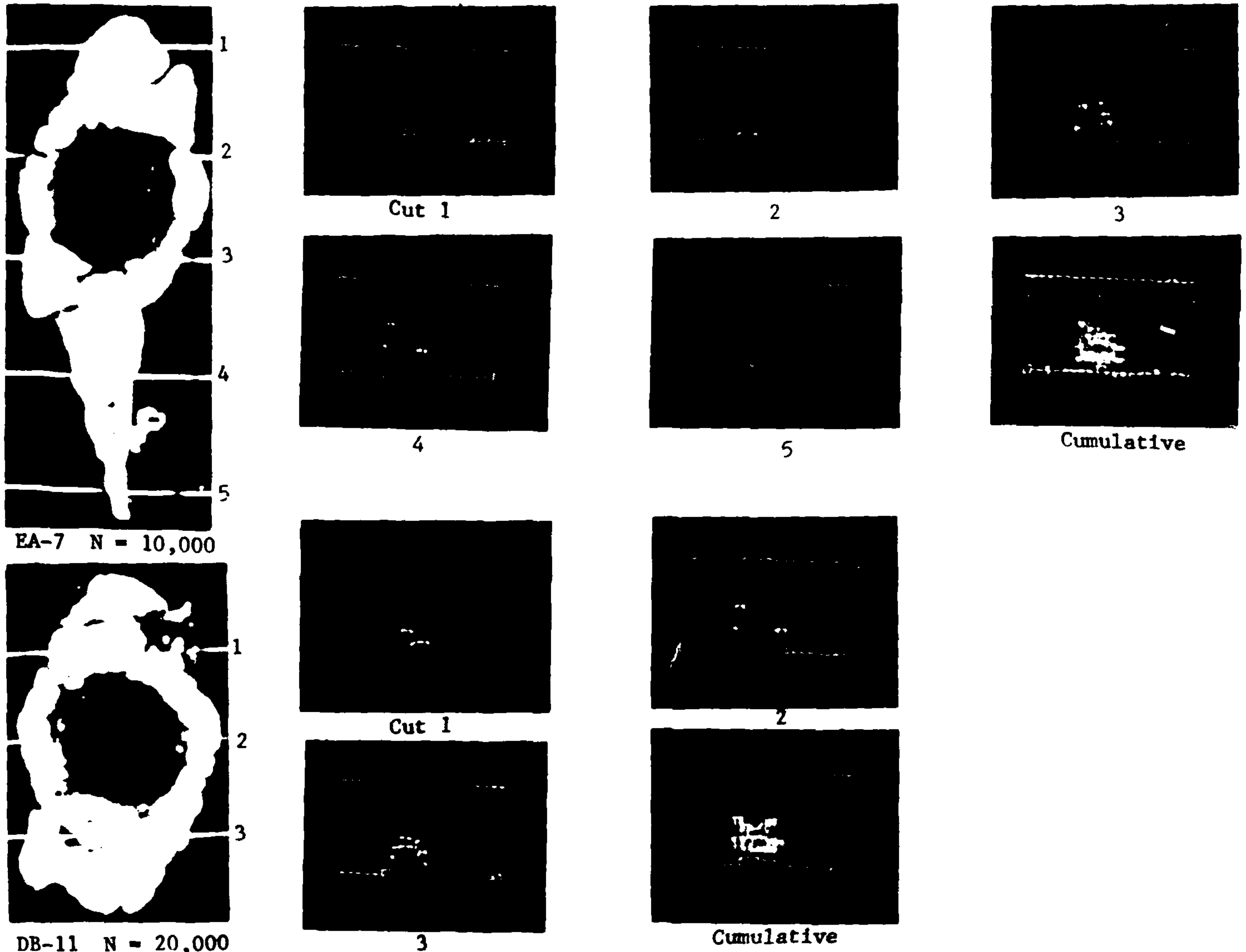


Figure E6b: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition A, 4-Bar Support (See Table XXXV, Vol. II)

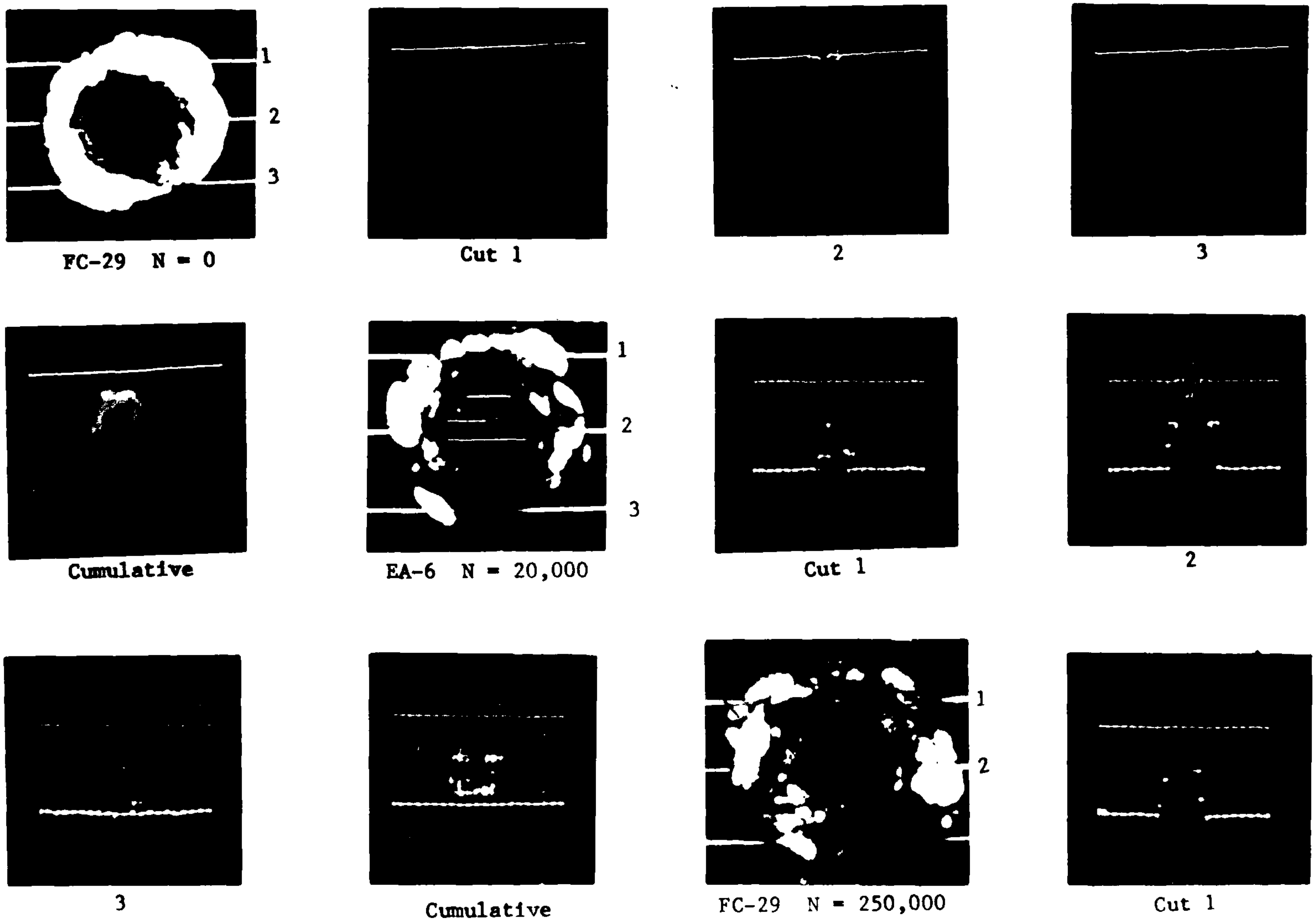


Figure E7a: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B, R = -0.3 (See Table XXXV, Vol. II)

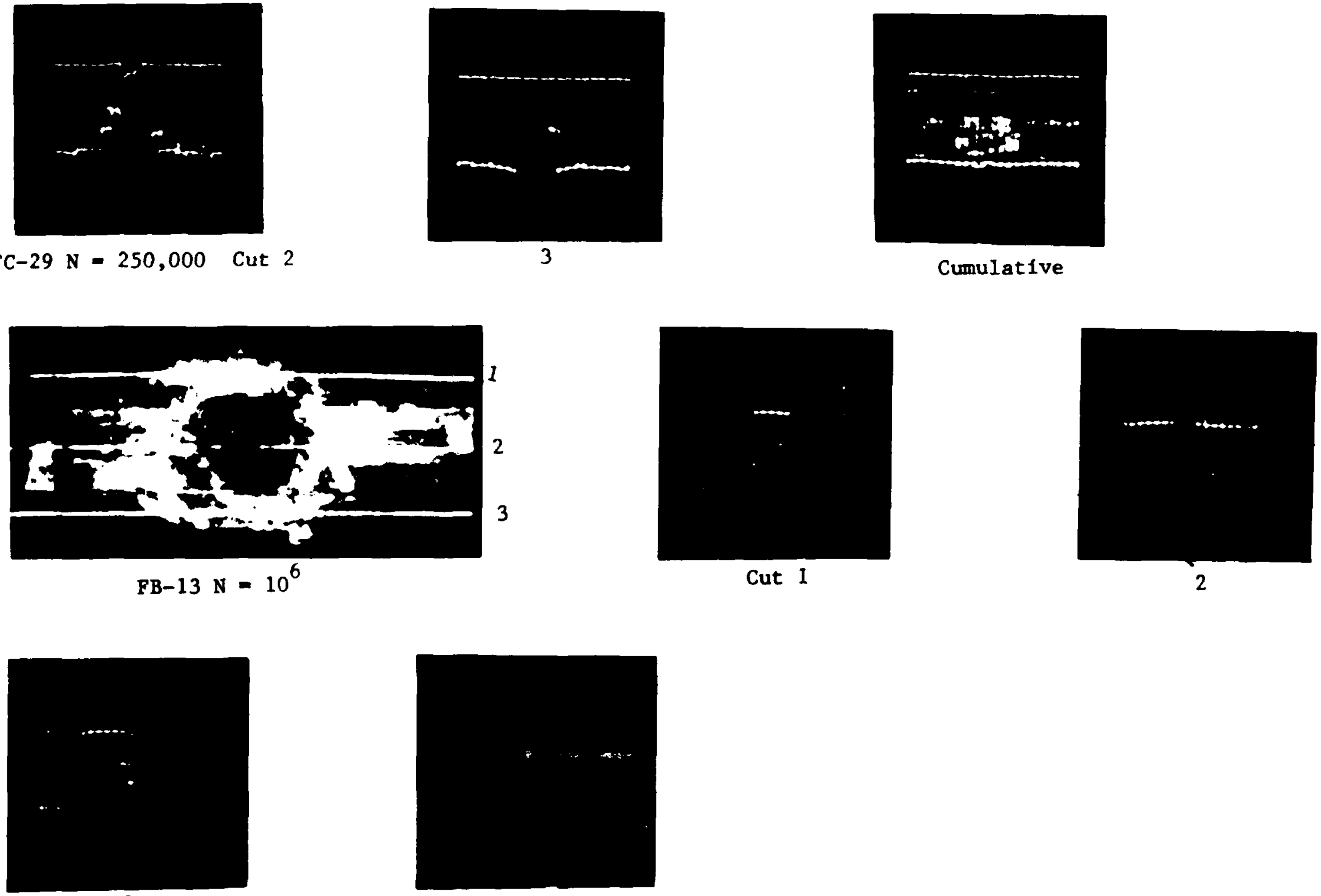


Figure E7b: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B, R = -0.3 (See Table XXXV, Vol. II)

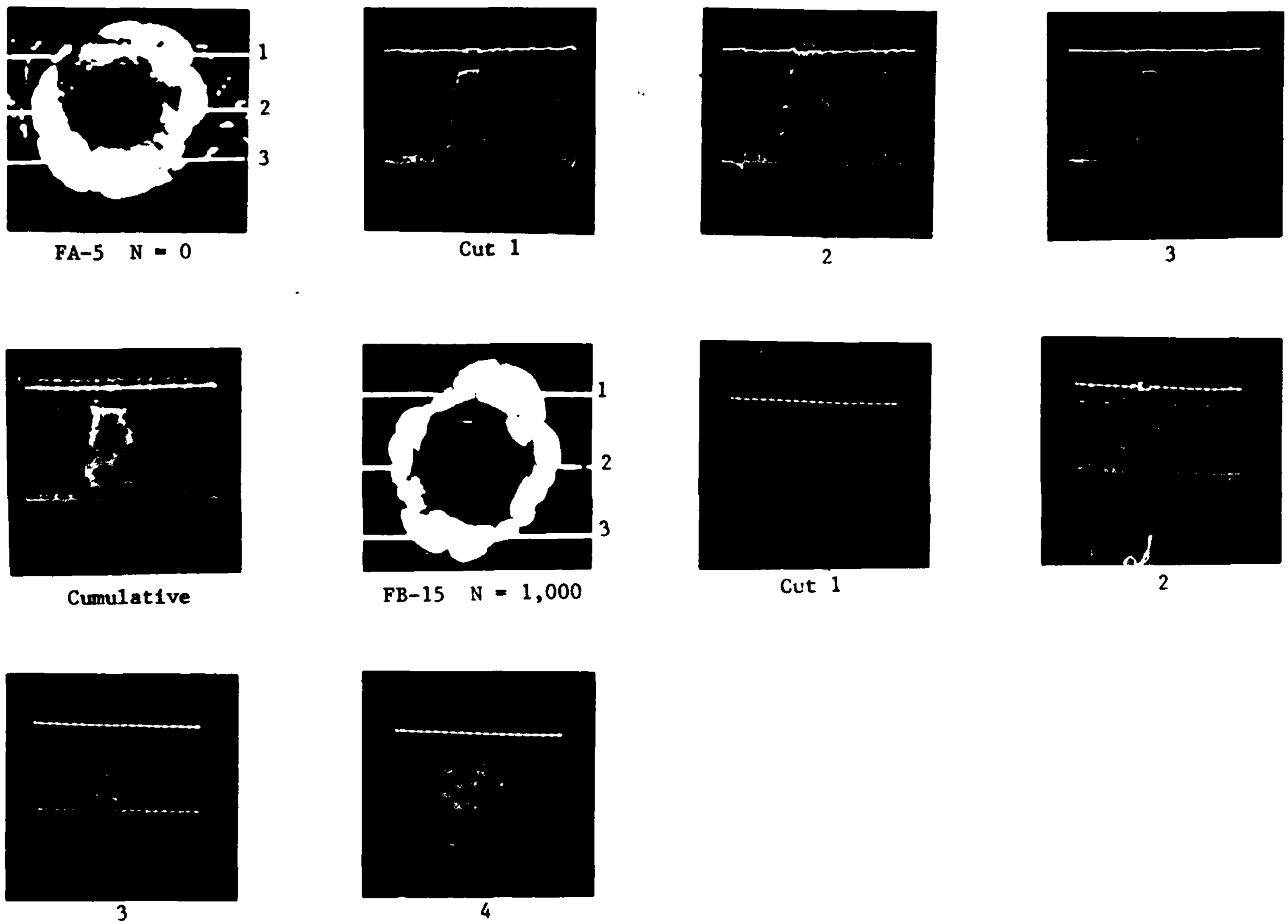


Figure E8a: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition C, 180°F (82°C) (See Table XXXV, Vol. II)

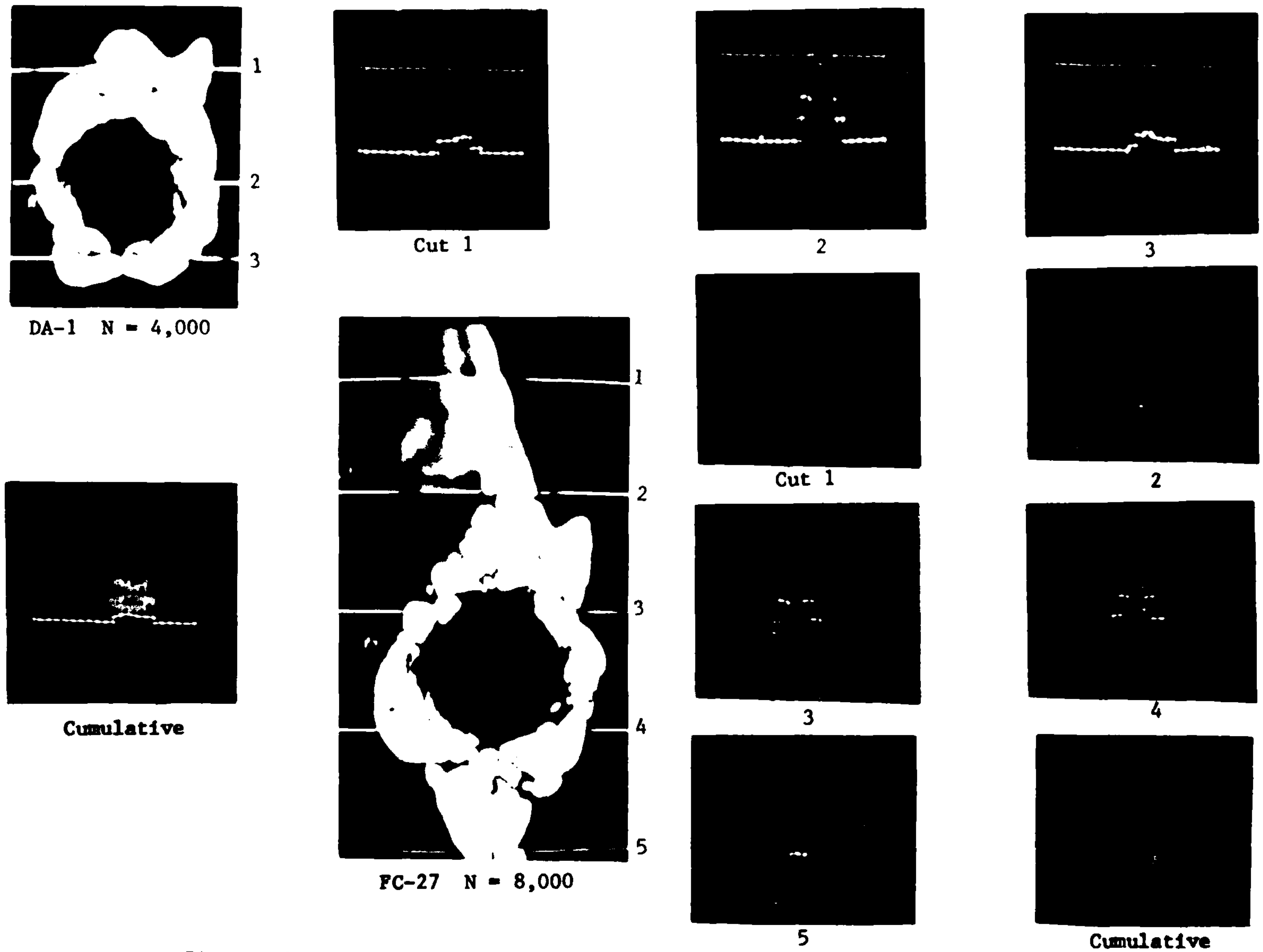


Figure E8b: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition C, 180°F (82°C) (See Table XXXV, Vol. II)

APPENDIX F

Damage Measurements of Specimens

Tested for Residual Strength

F1 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT $\pm$35ksi TO 4000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC. ID.	$N_o=0$			$N_1=4000$		
	WIDTH X,in.	LENGTH Y,in.	AREA $A,in.^2$	WIDTH X,in.	LENGTH Y,in.	AREA $A,in.^2$
AB-13	0.58	0.70	0.31	1.08	0.99	0.70
AB-14	0.63	0.73	0.35	0.76	0.88	0.45
AC-29	0.65	0.72	0.37	0.74	0.94	0.46
BA-1	0.66	0.83	0.43	1.21	0.97	0.94
BA-9	0.65	0.81	0.40	1.04	0.89	0.63
CB-11	0.66	0.78	0.41	0.83	1.04	0.60
CC-23	0.66	0.75	0.39	1.00	0.83	0.49
DA-3	0.62	0.91	0.42	1.05	0.92	0.68
DC-22	0.65	0.89	0.41	1.21	0.91	0.84
EA-7	0.70	0.73	0.41	1.33	1.12	1.06
EB-14	0.69	0.79	0.43	1.10	1.00	0.81
EC-25	0.63	0.88	0.42	1.07	1.01	0.78
EC-27	0.64	0.79	0.40	0.79	0.94	0.50
FB-19	0.63	0.72	0.35	0.69	0.88	0.41
FC-24	0.65	0.79	0.40	1.15	0.89	0.74
FC-25	0.61	0.75	0.38	0.84	0.94	0.56
GA-4	0.66	0.79	0.42	1.34	0.95	0.85
GB-16	0.63	0.76	0.37	0.90	0.91	0.55
HA-2	0.66	0.79	0.41	1.15	0.94	0.85
HA-7	0.60	0.72	0.32	0.70	0.82	0.40
HC-24	0.70	0.79	0.42	1.70	1.43	1.62
IA-1	0.70	0.83	0.46	1.24	1.04	0.89
IA-5	0.69	0.76	0.42	0.79	1.01	0.54

F2 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT $\pm$35 ksi TO 8000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	N_o=0			N_1=4000		
	WIDTH X,in.	LENGTH Y,in.	AREA A,in.^{2}	WIDTH X,in.	LENGTH Y,in.	AREA A,in.^{2}
AA-7	0.69	0.79	0.42	0.94	1.32	0.81
AA-9	0.69	0.81	0.45	a	a	a
AC-24	0.68	0.84	0.49	1.02	1.10	0.85
BA-6	0.68	0.80	0.48	a	a	a
BB-12	0.71	0.87	0.51	a	a	a
BC-30	0.70	0.78	0.42	0.82	0.97	0.58
CB-12	0.66	0.81	0.51	0.91	1.03	0.67
CB-16	0.62	0.78	0.37	0.94	0.94	0.55
DA-5	0.70	0.83	0.48	1.24	0.96	0.95
DB-18	0.66	0.74	0.42	0.86	1.01	0.67
DC-29	0.66	0.79	0.34	0.65	2.19	0.65
EA-5	0.64	0.78	0.45	1.99	1.51	2.35
EC-24	0.68	0.83	0.44	0.95	1.01	0.68
EC-29	0.64	0.74	0.40	0.97	1.06	0.72
FA-6	0.66	0.71	0.41	1.26	1.06	0.96
FB-11	0.88	0.99	0.65	1.66	1.12	1.26
FC-26	0.70	0.81	0.46	1.66	1.51	1.70
GA-6	0.71	0.76	0.47	2.16	1.66	2.28
GC-22	0.70	0.77	0.43	1.58	1.28	1.52
HB-15	0.61	0.72	0.42	a	a	a
HB-16	0.66	0.74	0.42	0.98	1.03	0.70
IB-15	0.69	0.76	0.43	1.12	1.06	0.85
IC-27	0.71	0.83	0.48	1.89	1.32	1.94

a = Specimen failed

F3 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT $\pm$35ksi TO 12,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	N_o=0			N_3=12,000		
	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}
AA-5	0.66	0.81	0.41	1.03	1.02	0.77
AC-27	0.61	0.76	0.36	0.72	1.01	0.57
BB-19	0.65	0.75	0.37	0.96	1.08	0.77
BC-21	0.69	0.84	0.43	0.86	1.06	0.74
CA-2	0.66	0.77	0.38	0.70	1.04	0.53
CA-6	0.64	0.81	0.39	a	a	a
CB-14	0.65	0.77	0.39	1.07	1.10	0.81
DA-2	0.64	0.84	0.42	a	a	a
DA-10	0.60	0.74	0.35	0.83	0.97	0.47
DB-15	0.68	0.79	0.42	1.68	1.45	1.64
DB-19	0.66	0.76	0.38	0.78	1.04	0.57
EA-4	0.65	0.79	0.42	a	a	a
FA-1	0.66	0.83	0.46	1.38	1.21	1.20
FB-18	0.66	0.78	0.41	a	a	a
GA-5	0.67	0.82	0.44	1.13	1.04	0.92
GB-18	0.63	0.77	0.38	0.90	0.94	0.64
HA-6	0.70	0.75	0.40	1.21	1.15	0.88
HA-8	0.63	0.76	0.35	1.31	1.16	1.00
HB-19	0.64	0.74	0.38	a	a	a
HC-21	0.70	0.85	0.48	1.97	1.52	1.93
IA-2	0.69	0.82	0.45	1.42	1.23	1.29
IA-6	0.65	0.81	0.39	1.04	1.01	0.69
IA-8	0.64	0.77	0.38	0.88	1.01	0.63

a = Specimen failed

F4 - DAMANGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT $\pm$35ksi TO 20,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	N_o=0			N_4=20,000		
	WIDTH X,in.	LENGTH Y,in.	AREA A,in.^{2}	WIDTH X,in.	LENGTH Y,in.	AREA A,in.^{2}
AA-3	0.70	0.76	0.42	0.91	1.07	1.05
AB-17	0.70	0.83	0.53	s	a	a
AC-25	0.65	0.82	0.40	1.09	1.30	0.80
BA-8	0.67	0.81	0.44	a	a	a
BB-14	0.72	0.81	0.47	1.20	1.04	0.89
BC-22	0.72	0.81	0.47	a	a	a
BC-28	0.63	0.73	0.37	a	a	a
CA-4	0.72	0.76	0.44	a	a	a
CA-9	0.68	0.76	0.42	a	a	a
CB-17	0.66	0.83	0.41	0.66	0.97	0.49
DB-14	0.68	0.84	0.43	1.14	1.23	0.92
EB-17	0.70	0.86	0.47	a	a	a
EC-26	0.64	0.81	0.39	a	a	a
FA-2	0.70	0.81	0.46	1.57	1.10	1.16
FB-15	0.64	0.77	0.39	1.77	1.45	1.74
FC-29	0.66	0.72	0.40	1.35	1.19	1.10
GC-23	0.72	0.78	0.48	1.01	1.30	0.97
GC-25	0.71	0.81	0.42	1.63	1.36	1.30
GC-24	0.66	0.79	0.40	1.27	1.06	0.91
HB-12	0.62	0.81	0.38	a	a	a
HC-29	0.65	0.73	0.39	a	a	a
IB-12	0.62	0.71	0.40	0.92	1.12	0.69
IB-14	0.63	0.81	0.38	a	a	a

a = Specimen failed

F5 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT $\pm$35ksi TO 40,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	N_o=0			N_5=40,000		
	WIDTH X,in.	LENGTH Y,in.	AREA A,in.^{2}	WIDTH X,in.	LENGTH Y,in.	AREA A,in.^{2}
A-26	0.63	0.72	0.36	0.93	1.21	0.71
AA-8	0.61	0.75	0.38	a	a	a
B-15	0.68	0.86	0.46	1.62	2.56	2.86
B-25	0.55	0.69	0.34	1.31	1.17	1.33
B-26	0.62	0.75	0.38	a	a	a
C-19	0.59	0.74	0.36	1.44	1.21	1.42
C-24	0.60	0.77	0.36	1.08	1.26	0.82
C-27	0.65	0.79	0.41	1.50	1.22	1.35
CA-3	0.66	0.85	0.43	a	a	a
D-13	0.64	0.78	0.40	a	a	a
D-26	0.59	0.80	0.55	a	a	a
E-9	0.58	0.68	0.33	1.30	1.46	1.23
E-15	0.65	0.83	0.61	a	a	a
E-30	0.59	0.73	0.34	2.17	1.45	2.16
F-7	0.61	0.70	0.36	a	a	a
F-27	0.61	0.72	0.36	0.93	1.21	0.86
G-1	0.63	0.80	0.40	a	a	a
G-3	0.61	0.75	0.39	a	a	a
G-9	0.59	0.68	0.36	1.32	1.35	1.53
G-15	0.65	0.83	0.41	a	a	a
H-3	0.61	0.75	0.39	a	a	a
H-30	0.62	0.72	0.55	1.97	1.50	2.50
I-16	0.63	0.76	0.38	1.14	1.28	0.93

a = Specimen failed

F6 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT $\pm$22ksi TO 1000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID.	$N_0 = 0$			$N_1 = 1000$		
	WIDTH X, in.	LENGTH Y, in	AREA A, in^2	WIDTH X, in.	LENGTH Y, in.	AREA A, in^2
JB-13	0.83	0.80	0.54	0.88	0.80	0.53
JB-16	0.71	0.70	0.42	0.74	0.72	0.44
JG-22	0.92	0.86	0.60	1.01	0.88	0.70
KA-9	0.81	0.84	0.58	1.06	0.88	0.69
KB-18	0.87	0.77	0.55	0.81	0.81	0.53
KE-27	0.75	0.81	0.51	0.81	0.81	0.54
LA-3	0.83	0.79	0.56	1.17	0.81	0.75
LA-9	0.87	0.86	0.59	0.97	0.87	0.67
MA-8	0.82	0.83	0.56	1.16	0.81	0.73
MC-23	0.80	0.88	0.60	1.08	0.86	0.61
MC-28	0.73	0.76	0.47	0.99	0.81	0.60
NA-4	0.86	0.83	0.57	1.23	0.87	0.84
NC-28	0.84	0.83	0.60	1.21	0.83	0.75
NC-30	0.77	0.77	0.54	1.12	0.80	0.70
PA-3	0.80	0.70	0.47	0.79	0.76	0.47
PA-9	0.79	0.78	0.54	1.11	0.79	0.67
QA-4	0.83	0.86	0.60	1.13	0.90	0.76
QA-6	0.83	0.90	0.61	1.13	0.90	0.78
QB-17	0.83	0.81	0.56	0.76	0.80	0.53
RA-2	0.86	0.88	0.65	1.44	0.89	0.89
RC-29	0.86	0.90	0.69	1.03	0.91	0.74
SA-7	0.80	0.80	0.55	0.97	0.83	0.65
SB-19	0.88	0.81	0.57	0.97	0.86	0.66

F7 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT $\pm$22ksi TO 5,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID	$N_0 = 0$			$N_2 = 5000$		
	WIDTH X, in	LENGTH Y, in	AREA A, in^2	WIDTH X, in	LENGTH Y, in	AREA A, in^2
JA-4	0.97	0.89	0.74	1.19	0.87	0.76
JA-5	0.88	0.81	0.58	1.74	0.86	0.94
KB-16	0.92	0.92	0.66	1.52	0.92	0.92
KC-24	0.82	0.88	0.57	1.01	0.88	0.67
KC-28	0.81	0.86	0.58	0.90	0.81	0.54
LA-2	0.86	0.90	0.61	1.38	0.86	0.78
LB-16	0.84	0.83	0.58	1.37	0.85	0.87
MA-6	0.84	0.81	0.56	1.99	0.88	1.11
MB-16	0.89	0.86	0.45	1.47	0.85	0.78
MC-22	0.74	0.74	0.49	1.79	0.84	0.98
NA-2	0.81	0.83	0.56	1.40	0.85	0.81
NC-22	0.79	0.88	0.57	1.77	0.83	1.02
NC-26	0.77	0.83	0.51	1.25	0.82	0.70
PB-15	0.72	0.74	0.44	0.82	0.74	0.69
PC-25	0.85	0.83	0.57	1.61	0.85	0.86
QA-1	0.87	0.90	0.58	1.34	0.88	0.52
QA-9	0.76	0.81	0.52	1.88	0.77	0.85
QC-28	0.80	0.89	0.57	1.41	0.88	0.84
RB-19	0.83	0.88	0.59	1.11	0.90	0.69
RB-20	0.47	0.80	0.49	1.12	0.77	0.54
RC-27	0.87	0.89	0.61	1.87	0.87	0.99
SB-13	0.91	1.00	0.72	1.20	0.94	0.81
SC-22	0.83	0.92	0.58	1.72	0.92	0.98

F8 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT $\pm$22ksi TO 10,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID	$N_0 = 0$			$N_3 = 10,000$		
	WIDTH X, in	LENGTH Y, in	AREA A, in^2	WIDTH X, in	LENGTH Y, in	AREA A, in^2
JC-27	0.87	0.92	0.70	1.49	0.89	0.84
JC-28	0.87	0.87	0.58	1.50	0.98	1.01
KA-2	0.83	0.87	0.57	2.04	0.89	2.30
KA-7	0.84	0.87	0.59	1.37	0.84	0.85
KC-22	0.81	0.80	0.52	1.39	0.84	0.81
LA-7	0.83	0.83	0.55	1.49	0.81	0.80
LC-23	0.83	0.86	0.58	1.57	0.88	0.96
LC-27	0.79	0.85	0.51	1.50	0.86	0.98
MC-25	0.78	0.77	0.51	1.11	0.93	0.71
MC-29	0.81	0.77	0.53	1.03	0.88	0.66
NB-13	0.81	0.79	0.50	1.14	0.83	0.67
NB-16	0.81	0.89	0.57	2.67	0.89	1.42
PA-1	0.77	0.67	0.42	1.41	0.83	0.80
PA-4	0.83	0.74	0.46	1.46	0.85	0.79
PC-21	0.72	0.69	0.42	0.72	0.68	0.39
PC-27	0.76	0.74	0.49	0.88	0.76	0.46
QB-12	0.79	0.83	0.52	1.79	0.88	1.05
QC-23	0.83	0.89	0.59	1.77	0.87	0.81
RB-17	0.79	0.80	0.50	1.64	0.83	0.92
RC-23	0.95	1.00	0.73	1.86	0.94	1.06
SA-3	0.81	0.86	0.54	1.61	0.97	0.95
SA-5	0.77	0.76	0.47	1.11	0.81	0.63
SB-11	0.90	0.89	0.62	1.88	0.87	1.07

F9 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT $\pm$22ksi TO 20,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID	$N_0 = 0$			$N_4 = 20,000$		
	WIDTH X, in	LENGTH Y, in	AREA A, in^2	WIDTH X, in	LENGTH Y, in	AREA A, in^2
JB-11	0.81	0.83	0.54	1.30	0.98	0.92
JB-14	0.76	0.78	0.48	1.50	0.84	0.88
JB-15	0.80	0.83	0.52	1.00	0.89	0.64
KB-12	0.72	0.80	0.51	1.38	0.90	0.95
LA-4	0.81	0.81	0.53	2.00	0.96	1.21
LA-5	0.80	0.81	0.53	2.18	0.94	1.10
LC-31	0.70	0.77	0.42	1.41	0.86	0.84
MB-11	0.79	0.83	0.50	2.62	0.88	1.37
MB-13	0.83	0.84	0.53	2.02	0.94	1.09
MB-18	0.84	0.84	0.56	1.57	0.88	0.93
NA-6	0.87	0.92	0.62	1.41	0.96	0.97
NB-17	0.93	0.94	0.66	1.30	0.93	0.90
NB-19	0.79	0.85	0.54	1.12	1.01	0.74
PB-17	0.74	0.72	0.42	2.06	0.91	0.96
QB-13	0.86	0.92	0.59	2.01	0.95	1.20
QC-22	0.93	0.90	0.64	1.86	1.00	1.28
QC-30	0.80	0.73	0.49	1.68	0.82	0.84
RA-7	0.85	0.90	0.60	1.59	0.94	1.00
RC-22	0.96	0.97	0.74	1.42	0.98	1.02
RC-24	0.83	0.88	0.58	2.44	0.93	1.37
SA-9	0.90	0.85	0.59	a	a	a
SC-23	0.82	0.86	0.56	2.38	0.89	1.44
SC-27	0.81	0.86	0.60	2.19	1.05	1.28

F10 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT $\pm$22ksi TO 28,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID	N = 0			N = 28,000		
	WIDTH X,in	LENGTH Y,in	AREA A,in^2	WIDTH X,in	LENGTH Y,in	AREA A,in^2
JB-18	0.92	0.85	0.64	2.89	1.10	1.94
JC-23	0.86	0.88	0.56	2.48	1.05	1.52
JC-30	0.87	0.87	0.62	1.64	0.94	1.05
KA-5	0.84	0.86	0.57	2.39	0.94	1.33
KB-14	0.82	0.83	0.54	2.47	0.93	1.40
KB-17	0.84	0.82	0.54	2.57	1.04	1.63
LB-19	0.84	0.81	0.58	1.74	0.95	2.18
LC-26	0.85	0.80	0.53	2.54	1.01	1.49
MA-4	0.85	0.81	0.56	2.44	2.57	2.94
MB-15	0.69	0.67	0.36	0.88	0.75	0.42
NB-14	0.79	0.75	0.47	1.52	0.84	0.78
NB-18	0.83	0.86	0.56	2.52	1.00	1.46
PA-7	0.84	0.89	0.61	2.55	0.95	1.54
PB-12	0.85	0.83	0.56	2.59	1.03	1.57
PB-13	0.86	0.89	0.68	2.63	1.01	1.54
QC-24	0.81	0.80	0.51	1.16	0.88	0.45
QC-31	0.76	0.83	0.49	2.04	0.83	0.99
RA-5	0.91	0.91	0.62	2.61	0.94	1.49
RC-25	0.90	0.97	0.68	2.73	1.00	1.77
RC-31	0.76	0.81	0.48	2.54	1.19	1.60
SB-17	0.87	0.87	0.57	2.17	0.94	1.23
SB-18	0.81	0.90	0.58	2.21	0.98	1.34
SC-31	0.81	0.87	0.56	1.72	0.96	1.43

TABLE F11

DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED UNDER CONDITION A, 4-BAR SUPPORT FOR RESIDUAL STRENGTH DETERMINATION TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}	WIDTH X, in.	LENGTH Y. in.	AREA A, in.^{2}
		$N_o = 0$			$N_1 = 4,000$	
AB-14	0.70	0.88	0.49	0.93	1.26	0.88
AC-26	0.66	0.75	0.43	1.06	1.02	0.84
BA-7	0.61	0.68	0.35	0.57	0.82	0.39
BC-27	0.68	0.89	0.50	1.22	1.05	0.89
CA-2	0.67	0.81	0.47	1.90	1.23	1.52
CA-9	0.68	0.84	0.46	0.77	1.07	0.65
		$N_o = 0$			$N_2 = 8000$	
AB-16	0.59	0.70	0.34	0.86	0.90	0.54
AB-19	0.63	0.79	0.43	1.18	1.10	1.01
BA-4	0.62	0.73	0.36	1.10	1.15	1.00
CA-7	0.67	0.83	0.48	0.99	1.05	0.78
CA-10	0.70	0.85	5.00	1.17 1.26	1.08	0.96 1.09
CC-23	0.71	0.88	0.50	-	-	-
		$N_o = 0$			$N_3 = 12000$	
AA-7	0.68	0.77	0.46	1.24	1.26	1.28
AC-31	0.66	0.80	0.44	1.25	1.50	1.23
BB-11	0.70	0.84	0.49	2.07	1.38	2.22
BB-13	0.59	0.68	0.31	0.59	0.92	0.40
CC-21	0.68	0.83	0.49	1.83	1.48	1.91
CC-26	0.68	0.81	0.43	1.56	1.17	1.32

TABLE F12

DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED UNDER CONDITION B, R = -0.3 FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}	WIDTH X, in.	LENGTH Y. in.	AREA A, in.^{2}
		N_o = 0			N_1 = 4,000	
AB-12	0.70	0.84	0.50	0.70	1.30	0.68
AC-25	0.68	0.83	0.46	0.75	1.24	0.71
BC-22	0.69	0.86	0.46	0.70	1.19	0.63
BC-25	0.64	0.73	0.40	0.64	1.25	0.67
CB-16	0.57	0.67	0.31	0.57	0.99	0.48
CC-28	0.70	0.85	0.48	0.69	1.26	0.65
		N_o = 0			N_2 = 40,000	
AA-10	0.69	0.86	0.45	0.70	1.81	0.88
AB-20	0.59	0.71	0.36	0.64	1.59	0.73
BB-15	0.67	0.86	0.46	0.72	1.65	0.83
BB-19	0.68	0.80	0.45	0.72	1.66	0.86
CA-3	0.68	0.89	0.51	0.72	1.88	1.02
CB-13	0.68	0.87	0.50	0.72	1.73	0.91
		N_o = 0			N_3 = 250K	
AB-15	0.70	0.86	0.48	0.70	2.13	1.08
AC-24	0.67	0.88	0.51	0.72	2.14	1.10
BA-10	0.68	0.85	0.50	0.70 0.68	2.21 2.19	1.07 1.07
BC-31	0.68	0.89	0.49	0.72	2.00	0.93
CB-11	0.69	0.81	0.47	0.68	1.84	0.94
CB-15	0.71	0.86	0.50	0.68	1.99	0.98

TABLE F13

DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED UNDER CONDITION C, 180°F FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}	WIDTH X, in.	LENGTH Y. in.	AREA A, in.^{2}
		$N_o = 0$			$N_1 = 50$	
AA-3	0.68	0.87	0.47	0.88	0.91	0.58
AC-23	0.70	0.81	0.48	1.05	0.81	0.63
BB-20	0.66	0.84	0.45	0.68	0.88	0.47
BC-28	0.69	0.89	0.47	0.75	0.90	0.50
CB-14	0.69	0.80	0.48	0.72	0.91	0.54
CB-19	0.57	0.69	0.31	0.62	0.71	0.36
		$N_o = 0$			$N_2 = 300$	
AA-5	0.63	0.84	0.42	0.95	0.86	0.64
AB-13	0.68	0.90	0.49	0.70	0.93	0.56
BB-14	0.69	0.90	0.48	0.90	0.90	0.94
BB-17	0.66	0.79	0.39	0.68	0.88	0.48
CA-5	0.70	0.81	0.46	1.27	0.93	0.92
CC-30	0.67	0.86	0.52	1.08	0.95	0.78
		$N_o = 0$			$N_3 = 1000$	
AA-6	0.63	0.75	0.39	1.49	1.04	1.14
AC-30	0.56	0.68	0.31	0.81	0.79	0.50
BA-9	0.67	0.88	0.47	1.01	0.83	0.74
BB-16	0.62	0.79	0.32	0.66	0.79	0.41
CB-18	0.60	0.77	0.36	0.80	0.87	0.48
CB-20	0.61	0.77	0.41	0.87	0.77	0.50

TABLE F14

DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED UNDER CONDITION A, 4-BAR SUPPORT FOR RESIDUAL STRENGTH DETERMINATION TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}	WIDTH X, in.	LENGTH Y. in.	AREA A, in.^{2}
		$N_o = 0$			$N_1 = 1{,}000$	
DB-13	0.77	0.79	0.46	0.97	0.86	0.58
DC-26	0.83	0.87	0.59	1.22	0.86	0.69
EA-1	0.75	0.83	0.48	0.91	0.85	0.58
EB-22	0.80	0.77	0.47	1.17	0.84	0.66
FC-23	0.75	0.75	0.44	1.08	0.74	0.58
FC-28	0.82	0.74	0.46	0.92	0.79	0.60
		$N_o = 0$			$N_2 = 10{,}000$	
DB-18	0.68	0.58	0.31	0.99	0.53	0.40
DC-23	0.77	0.81	0.49	2.87	1.08	1.36
EA-7	0.80	0.75	0.52	2.28	0.87	1.10
EB-17	0.82	0.82	0.52	1.52	0.94	0.89
FA-10	0.77	0.78	0.51	1.68	0.90	0.98
FB-14	0.83	0.88	0.58	1.36	0.92	0.98
		$N_o = 0$			$N_3 = 20{,}000$	
DA-3	0.81	0.82	0.51	1.02	0.91	0.67
DB-11	0.75	0.74	0.44	1.59	0.96	1.08
EB-20	0.79	0.73	0.48	1.39	0.97	1.00
EC-23	0.73	0.75	0.41	1.03	0.83	0.63
FA-1	0.78	0.74	0.47	1.69	0.97	1.10
FA-2	0.77	0.72	0.47	2.59	0.99	1.48

TABLE F15

DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED UNDER CONDITION B, R = -0.3 FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}	WIDTH X, in.	LENGTH Y. in.	AREA A, in.^{2}
		N_o = 0			N_1 = 20,000	
EA-6	0.84	0.90	0.60	0.92	0.93	0.63
EC-24	0.68	0.59	0.34	0.70	0.57	0.33
DA-5	0.82	0.95	0.66	0.85	1.03	0.73
DB-19	0.73	0.78	0.44	0.76	0.83	0.47
FA-9	0.84	0.85	0.54	0.83	0.81	0.58
FC-27	0.72	0.72	0.43	0.85	0.78	0.50
		N_o=0			N_2=250K	
DA-8	0.79	0.77	0.47	1.06	1.10	0.94
DC-30	0.83	0.85	0.58	0.90	1.23	0.84
EA-9	0.79	0.78	0.49	0.88	1.06	0.66
EB-21	0.72	0.74	0.44	0.80	0.91	0.52
FA-7	0.77	0.83	0.50	0.85	0.99	0.64
FC-29	0.80	0.84	0.54	0.95	1.08	0.80
		N_o=0			N_3=10^6	
DB-14	0.81	0.79	0.52	0.97	1.14	0.90
DB-15	0.77	0.79	0.48	1.10	1.94	1.14
EB-16	o.81	0.88	0.56	0.95	1.22	0.92
EC-31	0.75	0.71	0.44	1.02	1.16	0.98
FB-13	0.77	0.78	0.49	0.84	1.32	1.00
FB-20	0.79	0.84	0.56	0.99	2.53	1.50

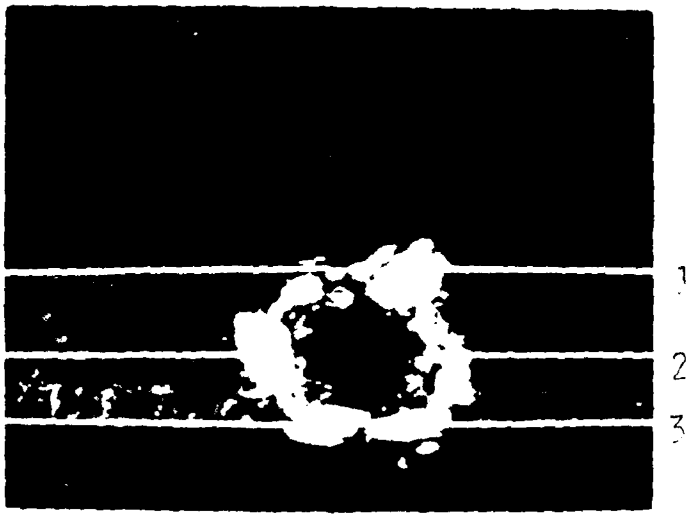
TABLE F16

DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED UNDER CONDITION C, 180°F FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in.^{2}	WIDTH X, in.	LENGTH Y. in.	AREA A, in.^{2}
		N_o = 0			N_1 = 1,000	
DB-12	0.83	0.83	0.54	1.53	0.90	0.93
DE-22	0.77	0.81	0.44	0.91	0.91	0.61
EB-12	0.80	0.78	0.50	1.05	0.88	0.65
EB-19	9.72	0.77	0.44	0.99	0.83	0.65
FB-15	0.73	0.74	0.44	0.94	0.82	0.58
FC-21	0.71	0.77	0.40	0.85	0.72	0.47
		N_o=0			N_2=4000	
DA-1	0.74	0.70	0.44	1.23	0.87	0.86
DB-20	0.77	0.77	0.44	1.40	1.01	0.97
EC-28	0.74	0.85	0.50	1.08	0.86	0.73
EC-29	0.80	0.83	0.54	1.42	0.98	0.92
FA-5	0.83	0.84	0.52	0.95	0.95	0.68
FA-6	0.72	0.77	0.46	0.98	0.76	0.51
		N_o=0			N_3=8000	
DA-10	0.83	0.84	0.57	3.38	1.06	2.29
DB-16	0.83	0.87	0.56	1.26	1.12	1.12
EA-5	0.88	0.84	0.58	1.61	1.04	1.07
EC-27	0.86	0.86	0.59	3.45	1.12	2.47
FB-11	0.83	0.88	0.58	1.12	1.06	0.84

APPENDIX G

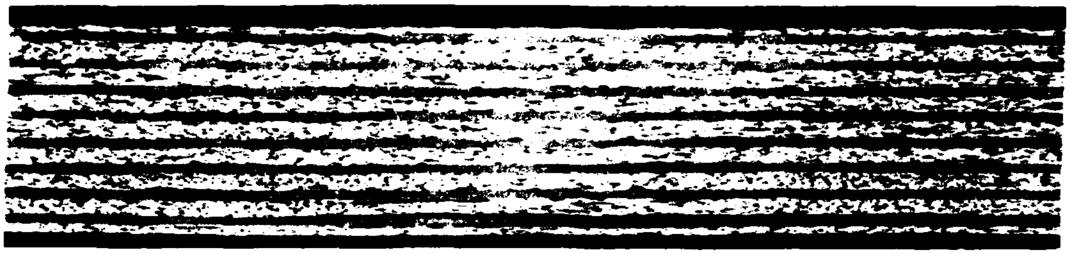
Damage as Determined by Metallographic Sectioning



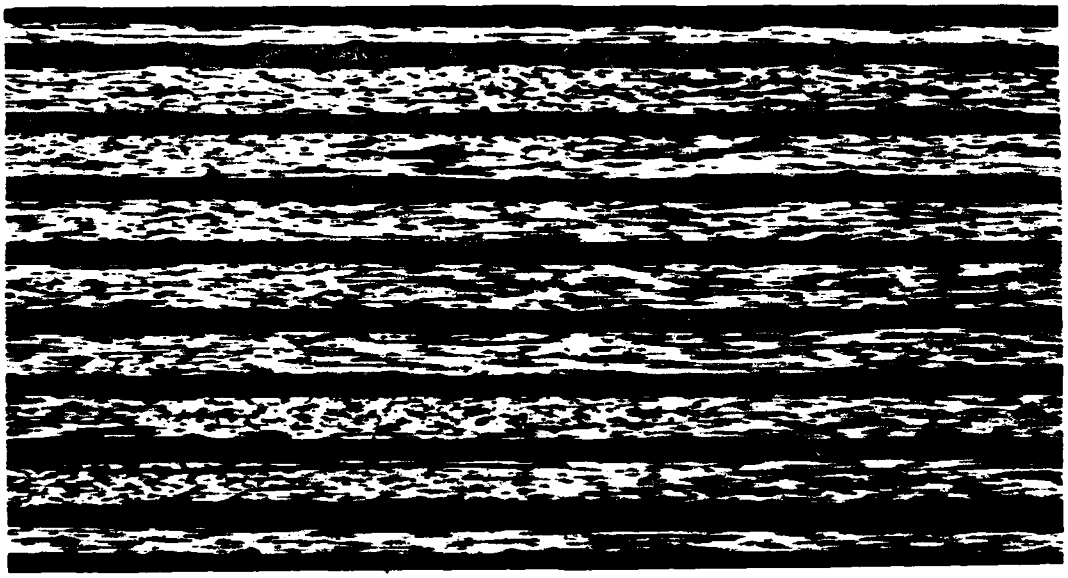
C-SCAN

CUMULATIVE B-SCAN

24-PLY SPEC: CB-11 N_1 = 4,000 CYCLES



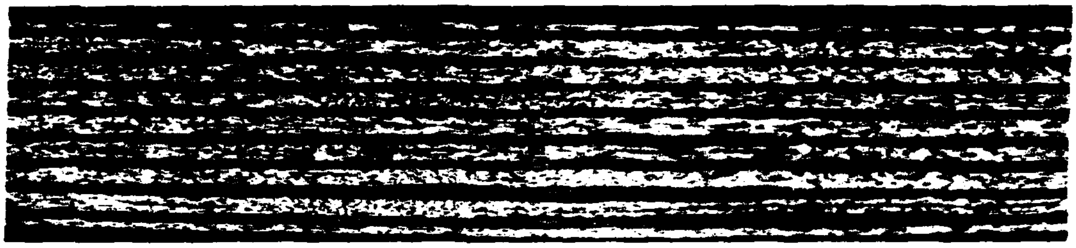
C11-1-1 10X



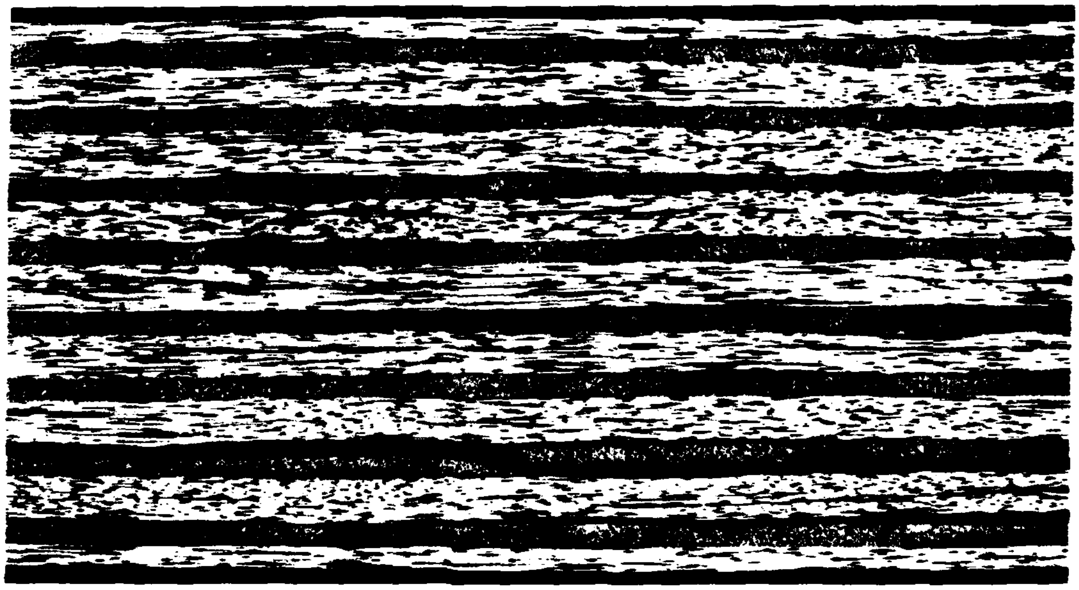
C11-1-2 25X

LOCATION: 1.12 IN. DAMAGE LENGTH: 0.628

B-SCAN AT 1.15 IN.

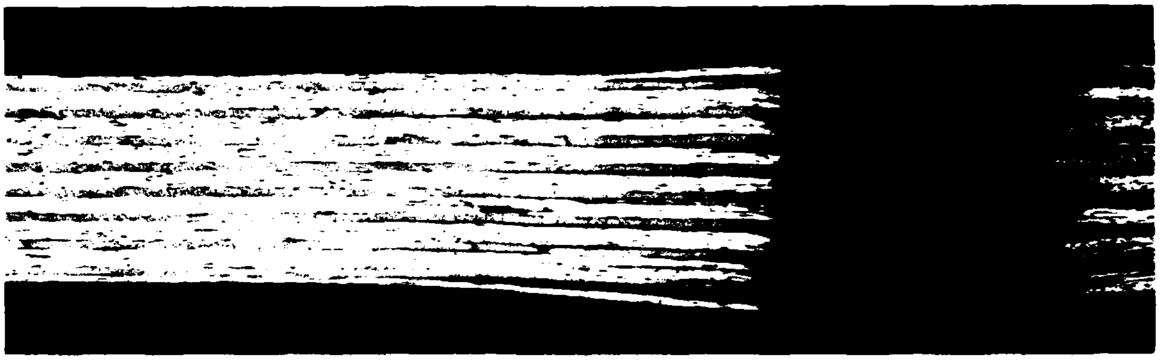


C11-2-1 10X

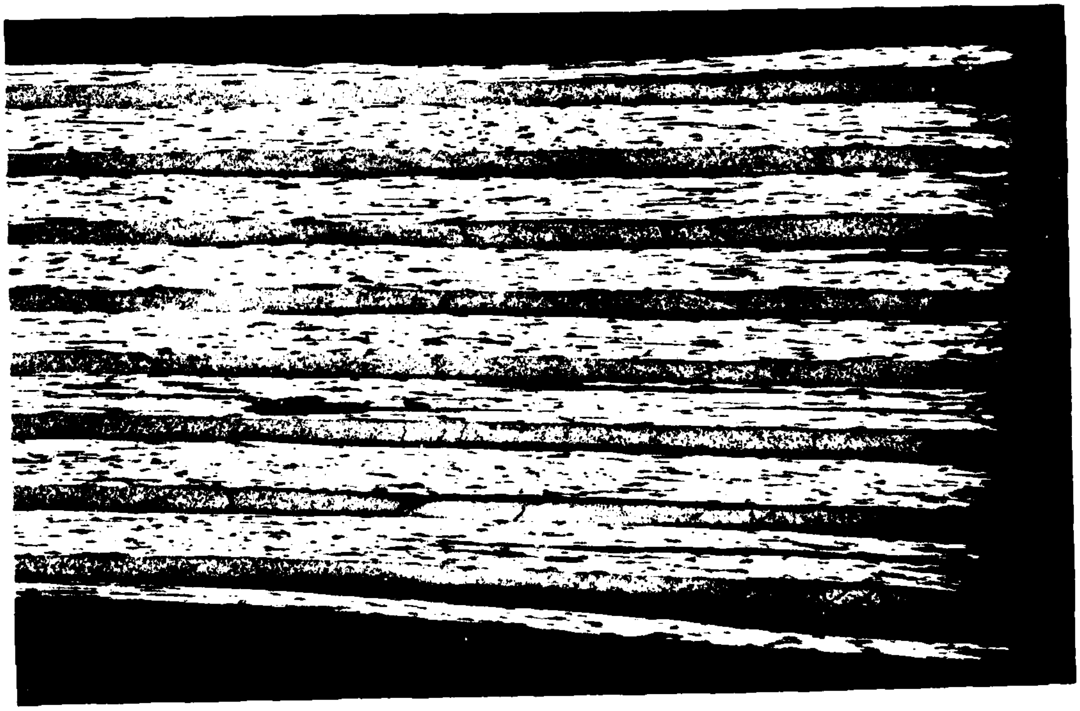


C11-2-2 25X

LOCATION: 1.22 IN. DAMAGE LENGTH: 0.704

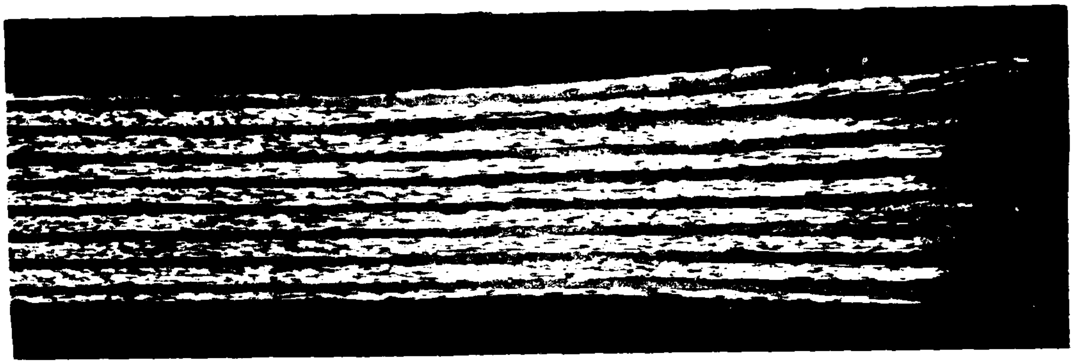


C11-3-1A 10X

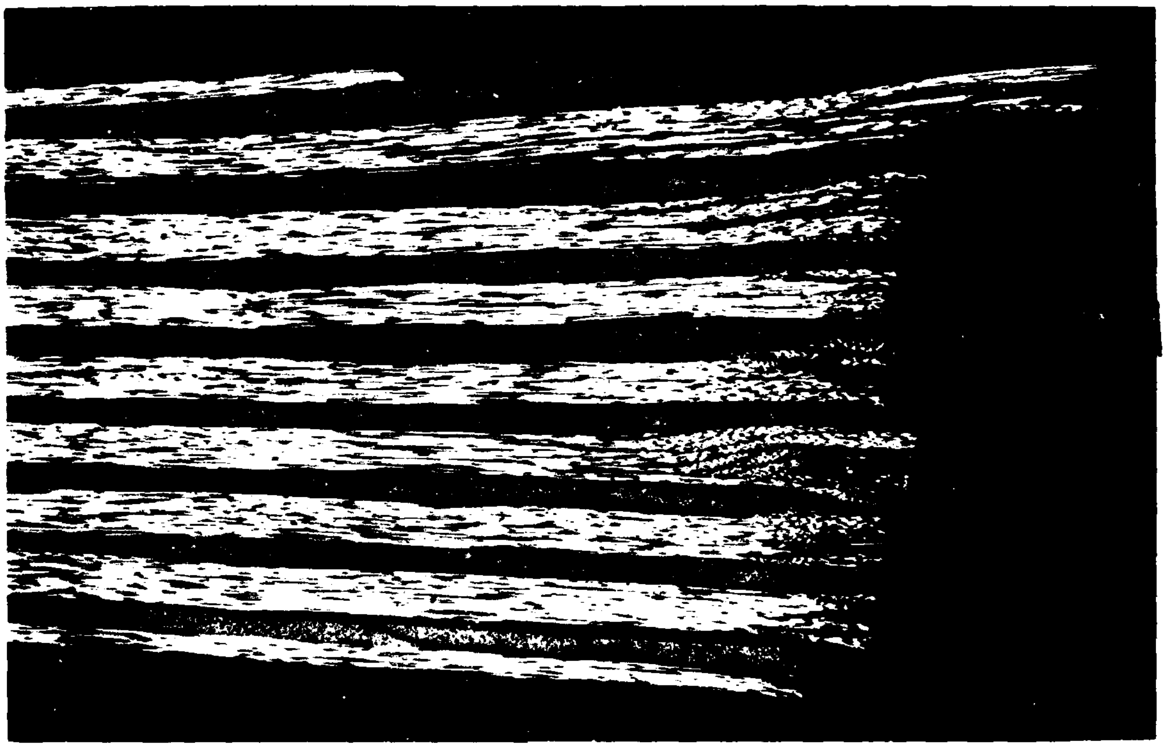


C11-3-2A 25X

LOCATION: 1.32 IN. DAMAGE LENGTH: 0.757



C11-3-1B 10X



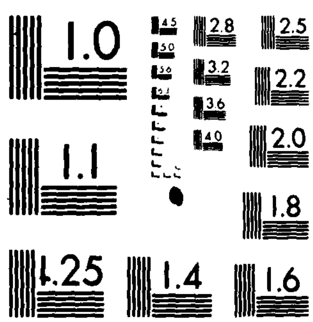
C11-3-2B 25X

LOCATION: 1.32 IN. DAMAGE LENGTH: 0.757

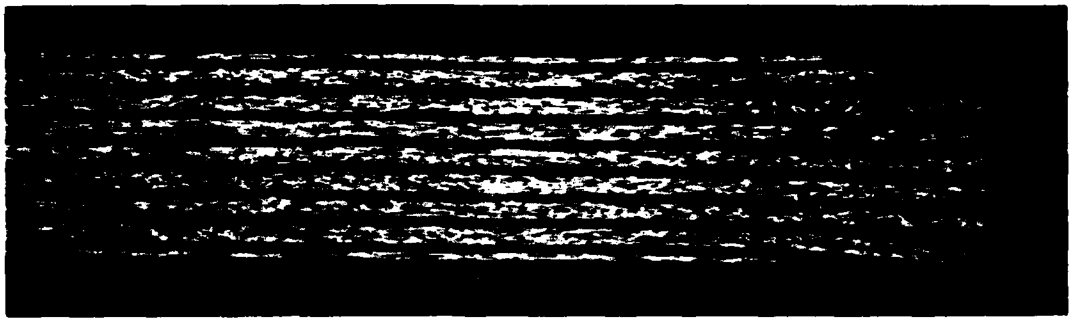
AD-A115 185 LOCKHEED-CALIFORNIA CO BURBANK F/G 11/4
ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC--ETC(U)
JUL 81 K N LAURAITIS, J T RYDER, D E PETTIT F33615-77-C-3084
UNCLASSIFIED LR-28360-19 AFWAL-TR-79-3095-VOL-3 NL

3 of 5

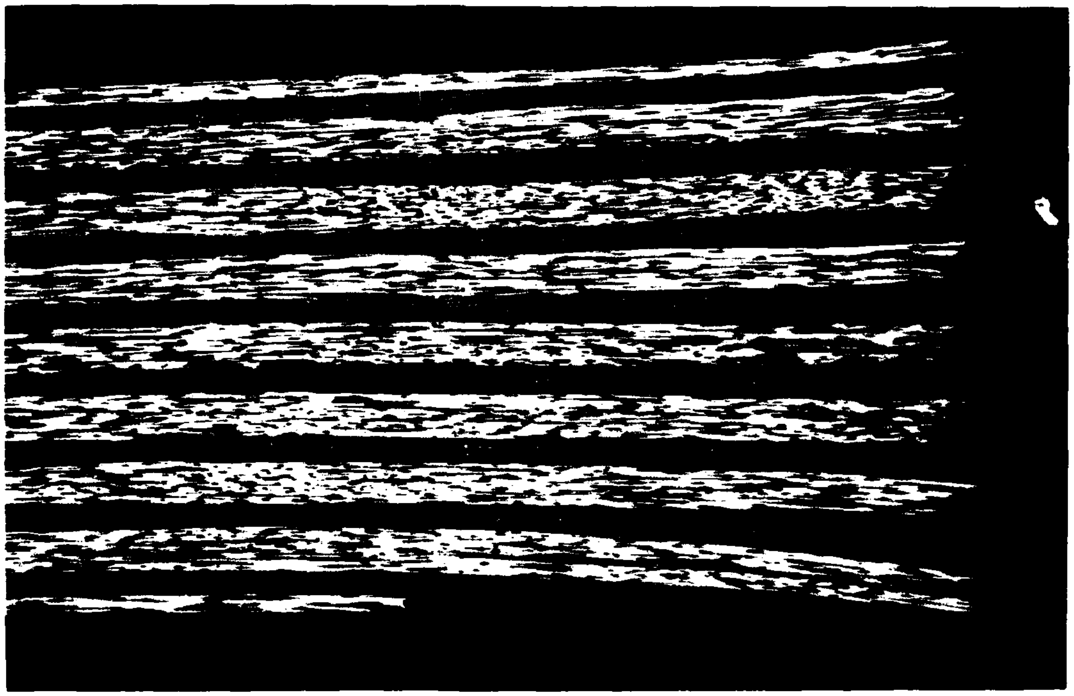
11/5/85



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

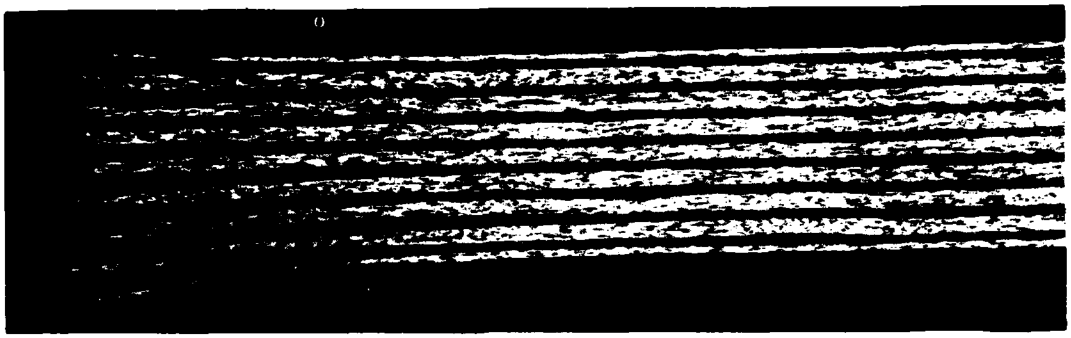


C11-4-1A 10X

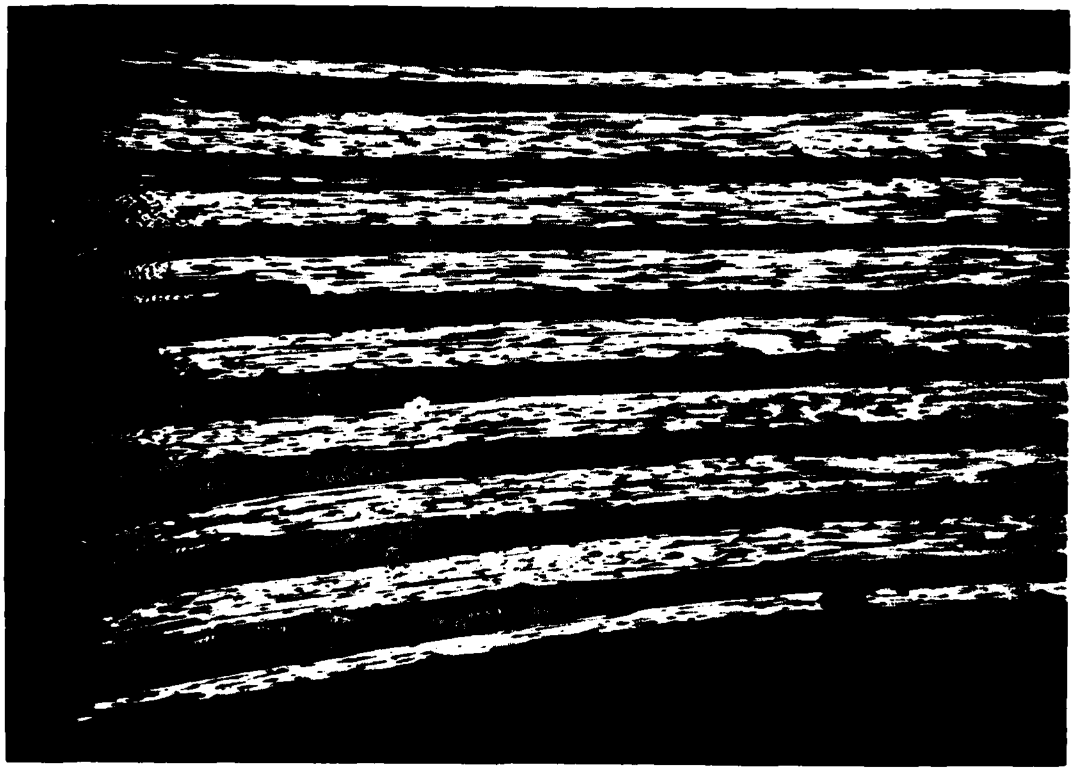


C11-4-2A 25X

LOCATION: 1.42 IN. DAMAGE LENGTH: 0.865



C11-4-1B 10X

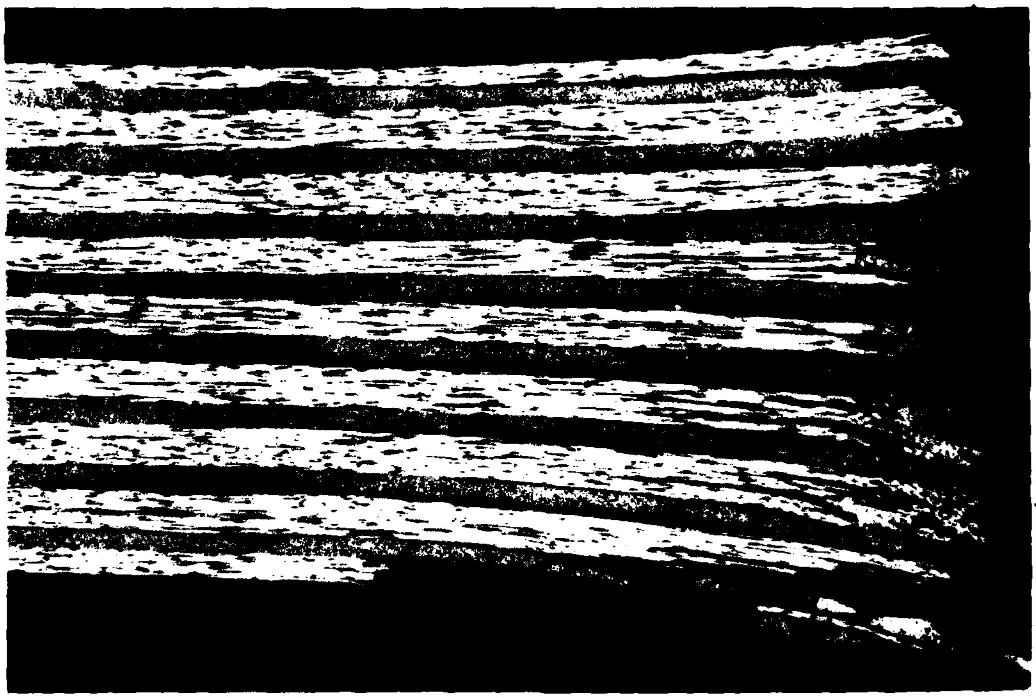


C11-4-2B 25X

LOCATION: 1.42 IN. DAMAGE LENGTH: 0.865

LOCATION: 1.52 IN. DAMAGE LENGTH: 0.903

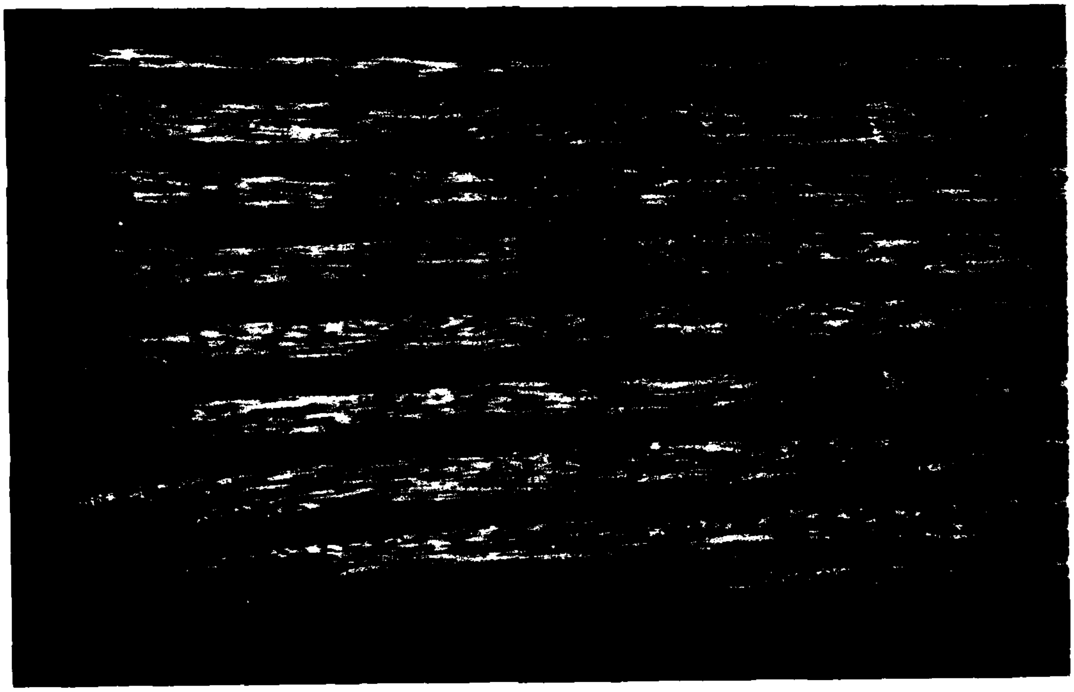
C11-5-1A 10X



C11-5-2A 25X

B-SCAN AT CENTER

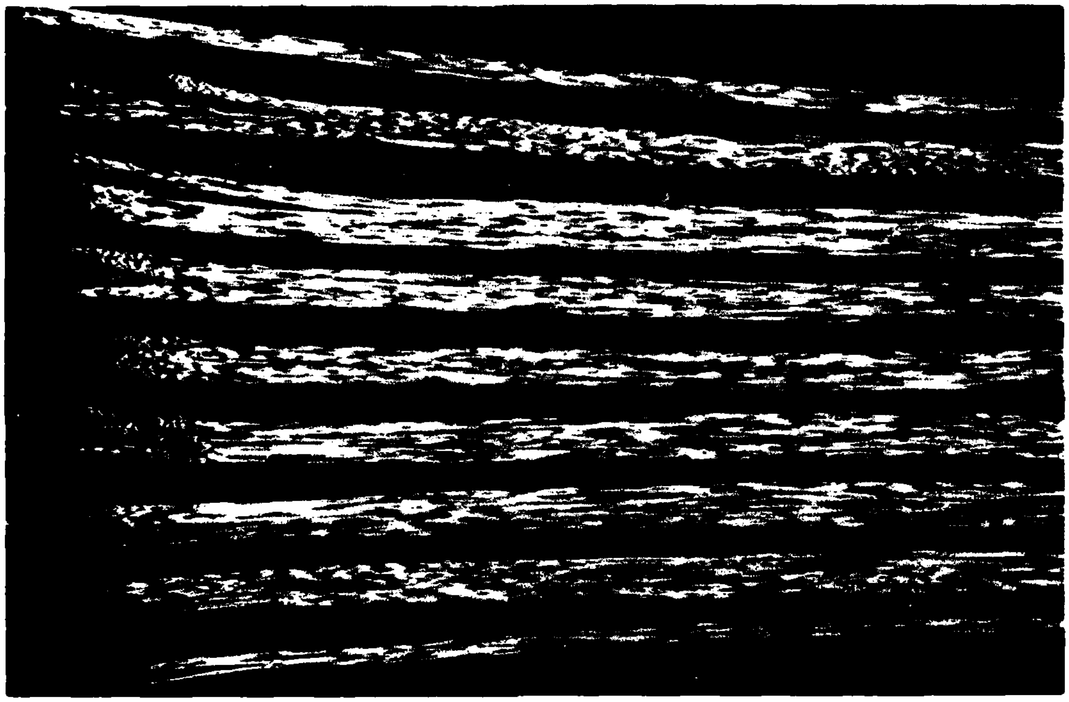
C11-5-1B 10X



C11-5-2B 25X

LOCATION: 1.52 IN. DAMAGE LENGTH: 0.903

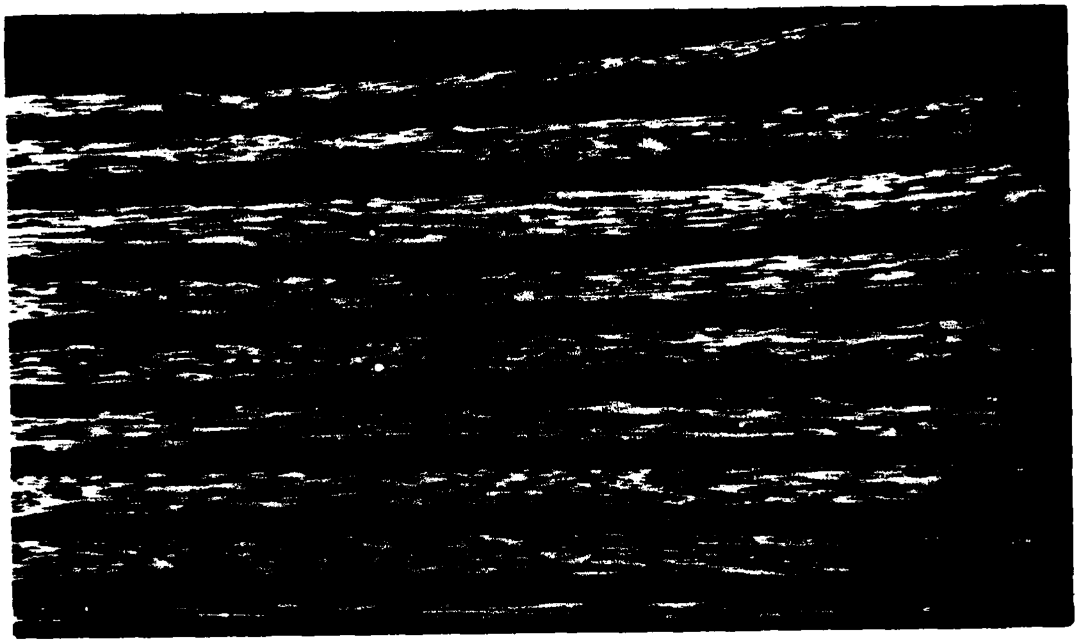
C11-6-1A 10X



C11-6-2A 25X

LOCATION: 1.62 IN. DAMAGE LENGTH: 0.867

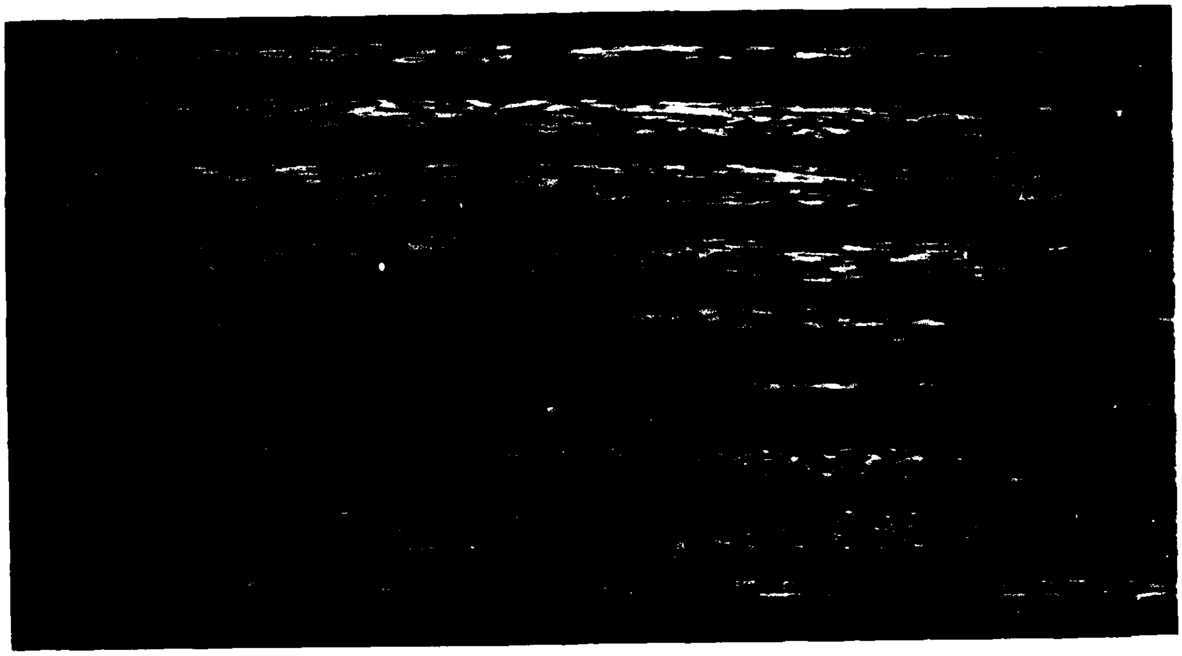
C11-6-1B 10X



C11-6-2B 25X

LOCATION: 1.62 IN. DAMAGE LENGTH: 0.867

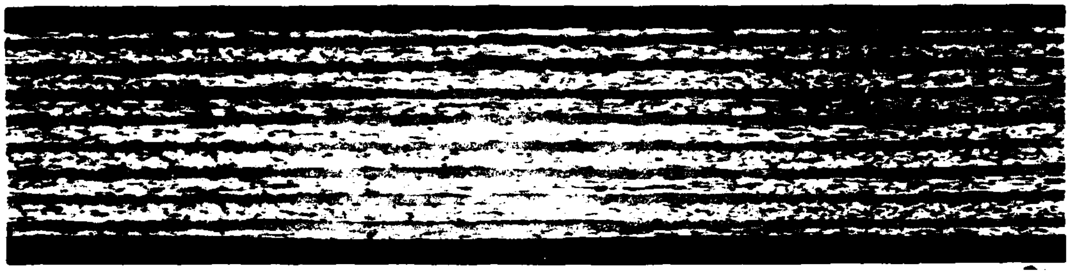
C11-7-1 10X



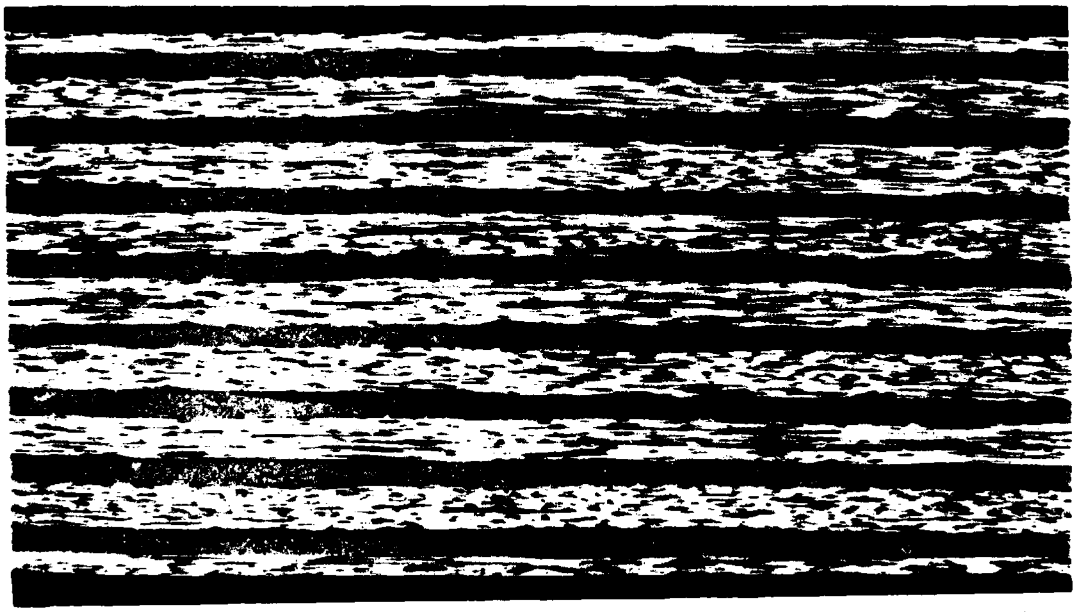
C-1-7-2 25X

B-SCAN AT 1.78 IN.

LOCATION: 1.72 IN. DAMAGE LENGTH: 0.653



C11-8-1 10X



C11-8-2 25X

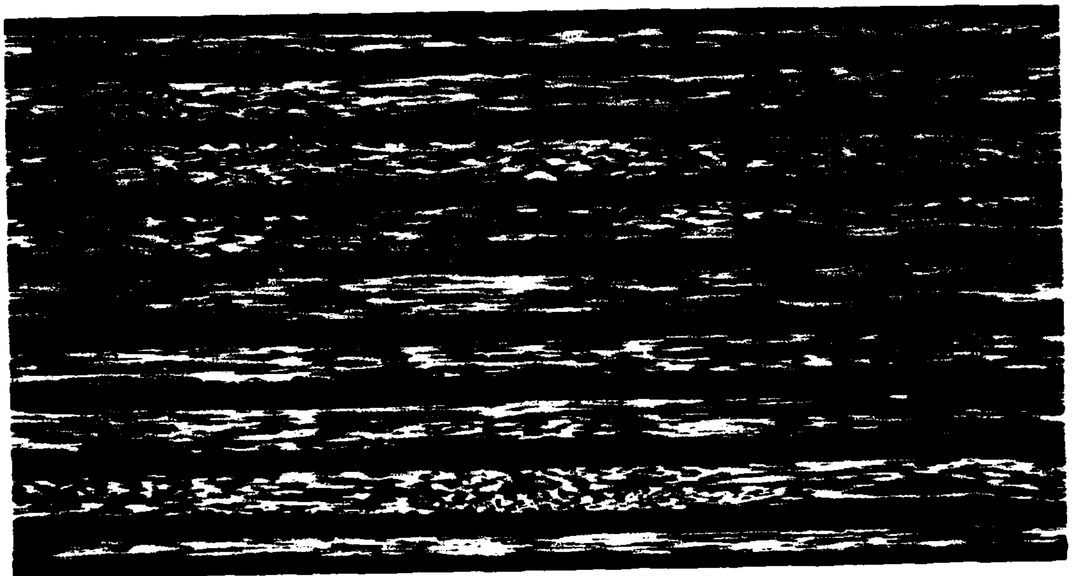
LOCATION: 1.82 IN. DAMAGE LENGTH: 0.290

C11-9-1 10X

C11-9-2 25X

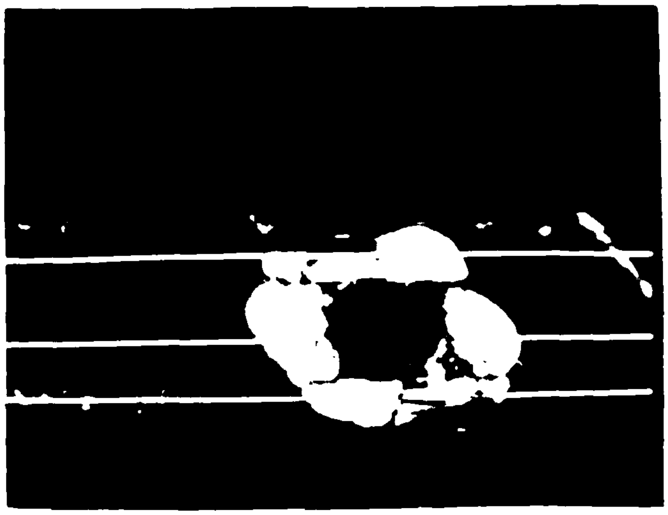
LOCATION: 1.92 IN. DAMAGE LENGTH: No Damage

C11-10-1 10X

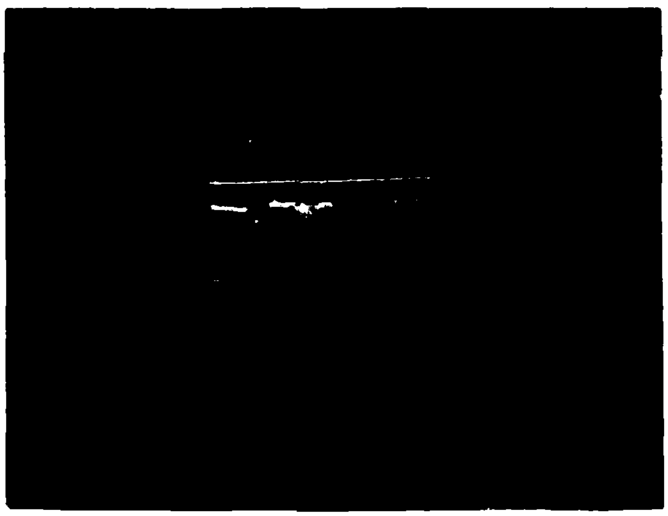


C11-10-2 25X

LOCATION: 2.02 IN. DAMAGE LENGTH: NO DAMAGE



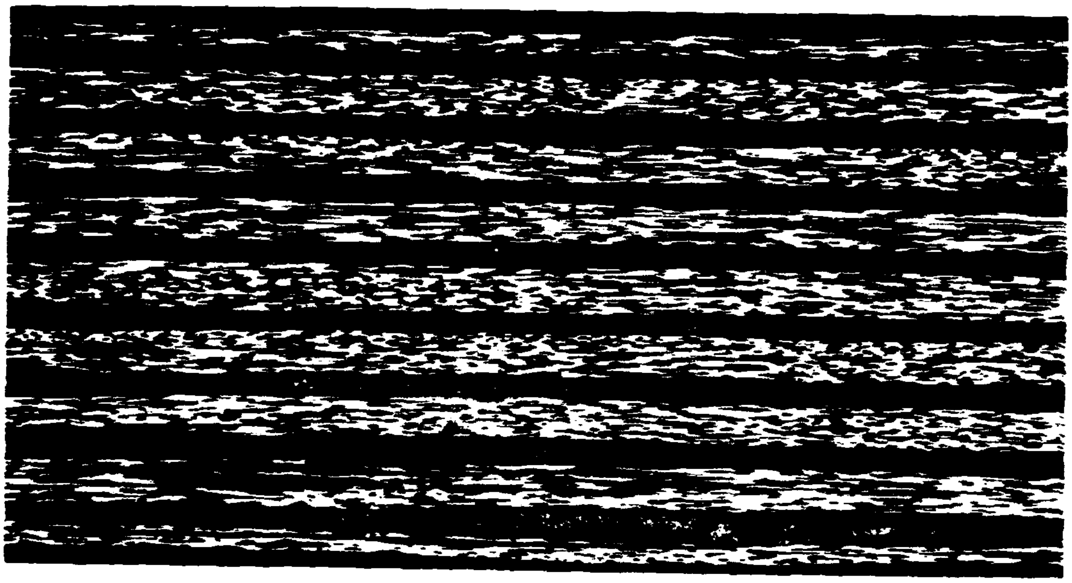
C-SCAN



CUMULATIVE B-SCAN

SPEC: D-19 N_3 = 12,000 CYCLES

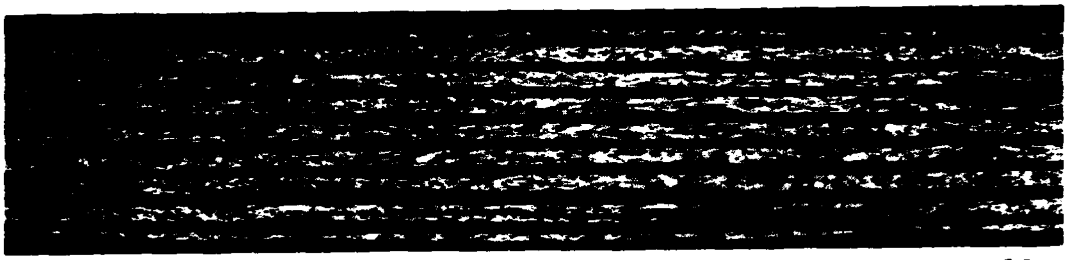
D19-1-1 10x



D19-1-2 25x

LOCATION: 1.15 IN. DAMAGE LENGTH: 0.659 IN.

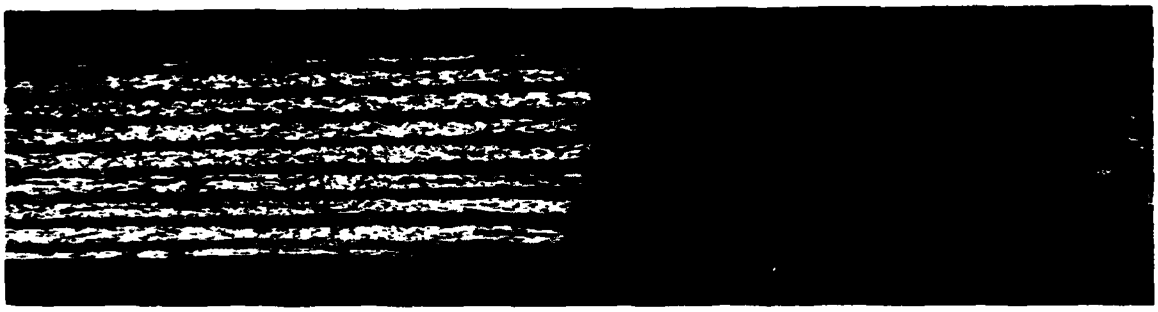
B-SCAN
@1.12 IN.



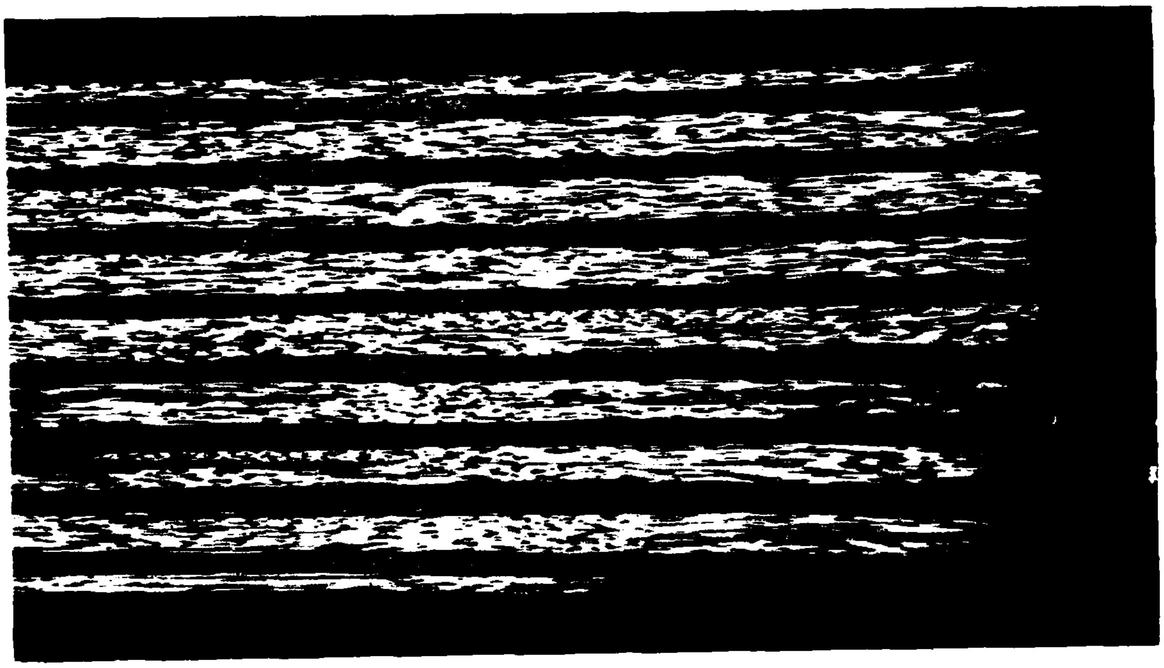
D19-2-1 10x

D19-2-2 ≃ 25x

LOCATION: 1.25 IN. DAMAGE LENGTH 0.858 IN.

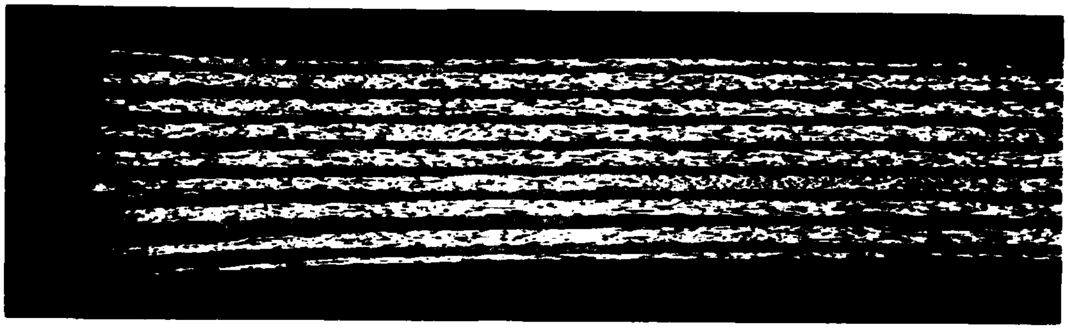


D19-3-1A 10x

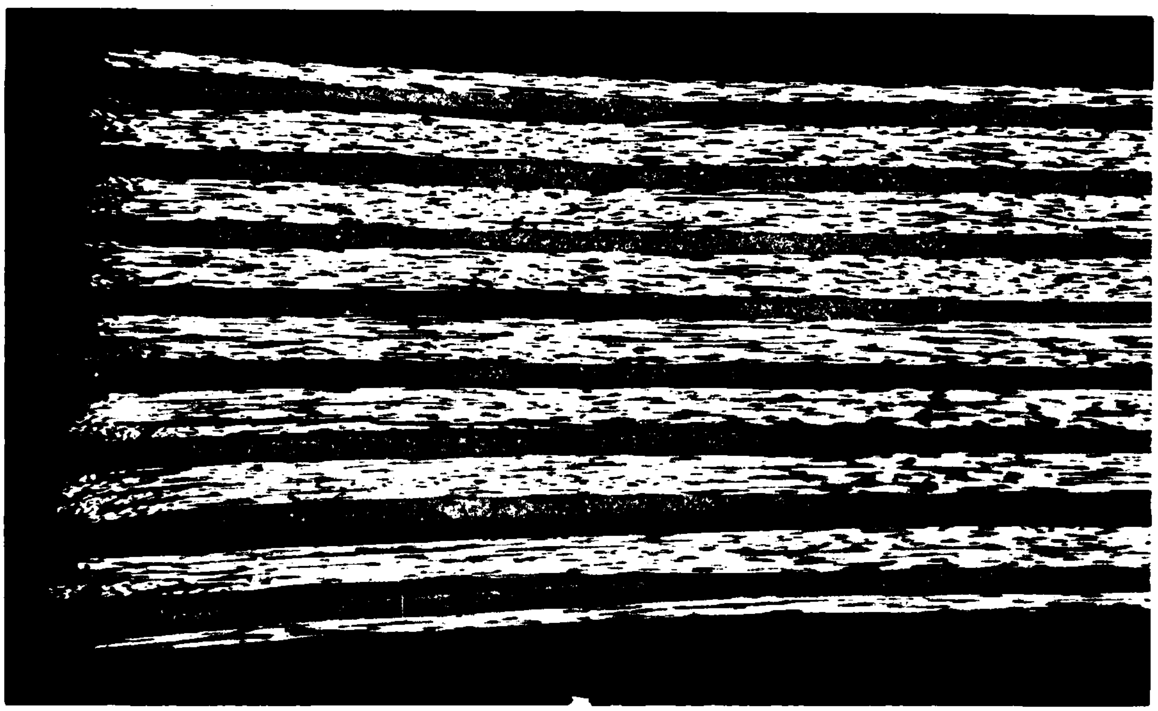


D19-3-2A 25x

LOCATION: 1.35 IN. DAMAGE LENGTH 0.908 IN.

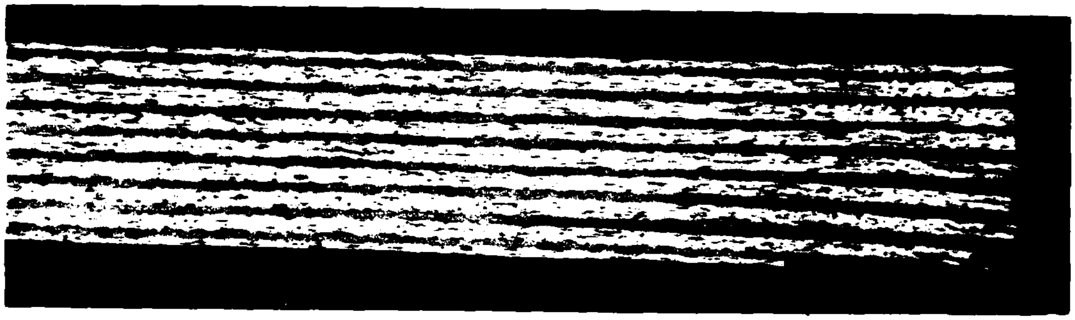


D19-3-1B 10x

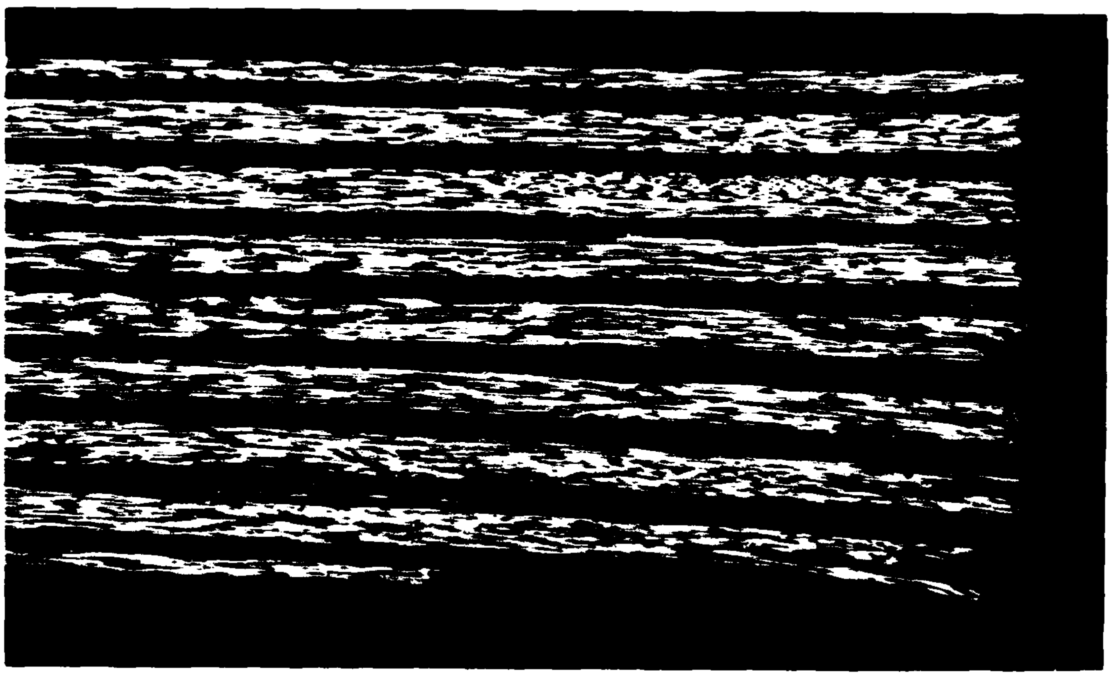


D19-3-2B 25x

LOCATION: 1.35 IN. DAMAGE LENGTH 0.908 IN.



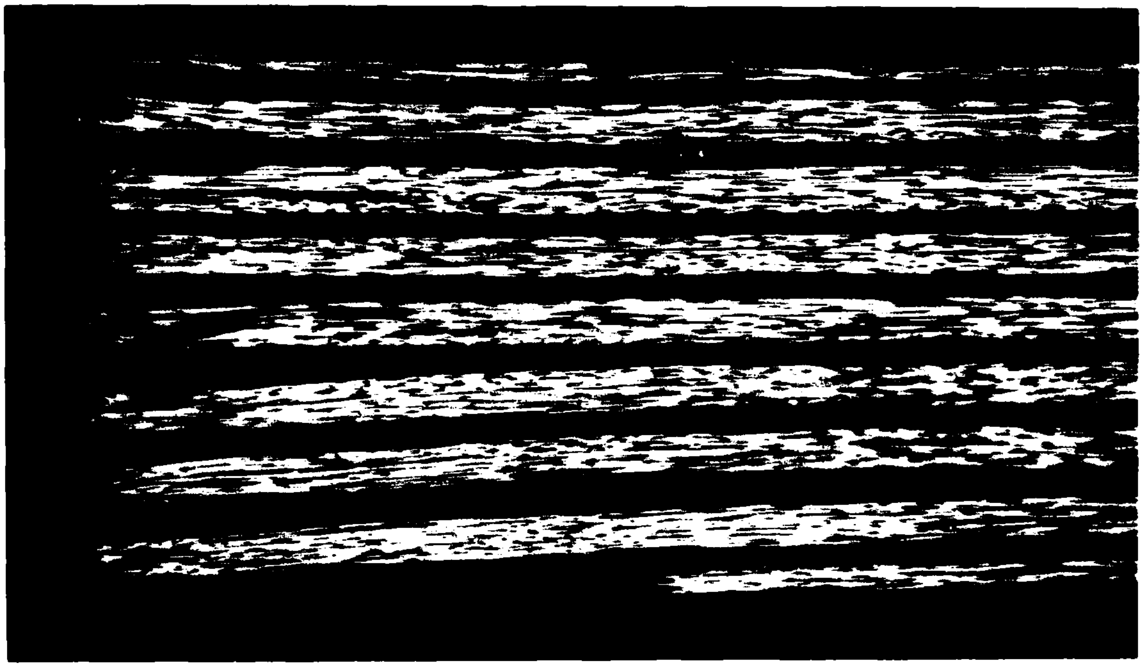
D19-4-1A 10x



D19-4-2A 25x

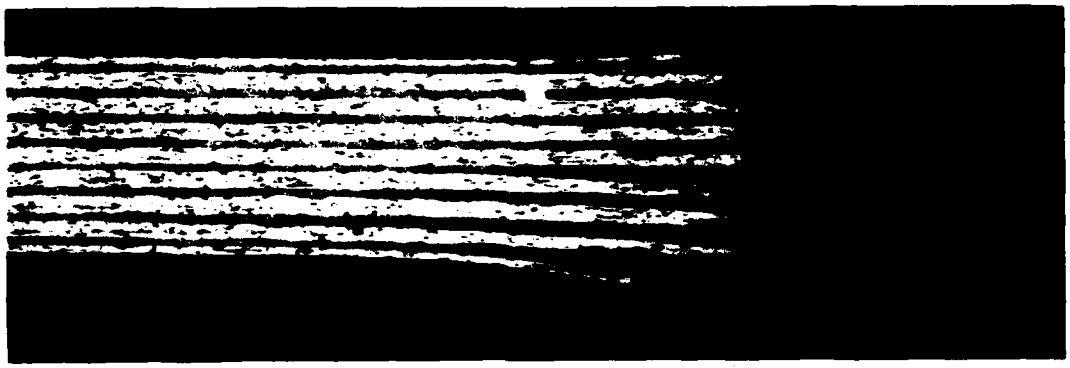
LOCATION: 1.45 IN. DAMAGE LENGTH 1.007 IN.

D19-4-1B 10x

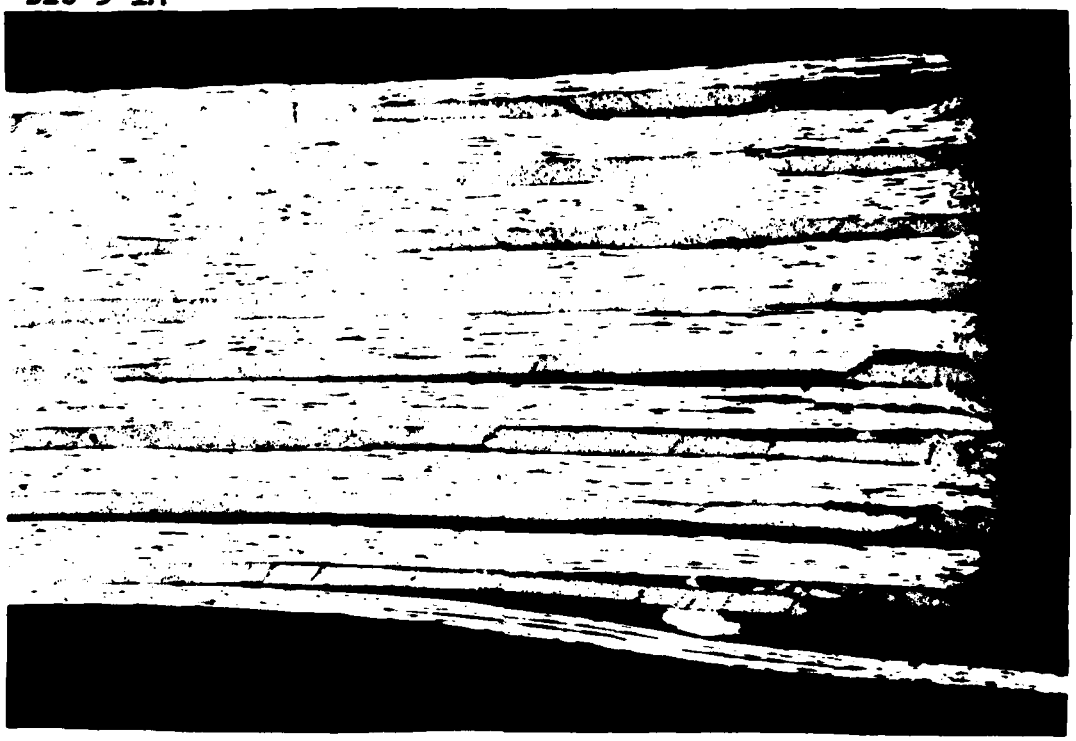


D19-4-2B 25x

LOCATION: 1.45 IN. DAMAGE LENGTH 1.007 IN.



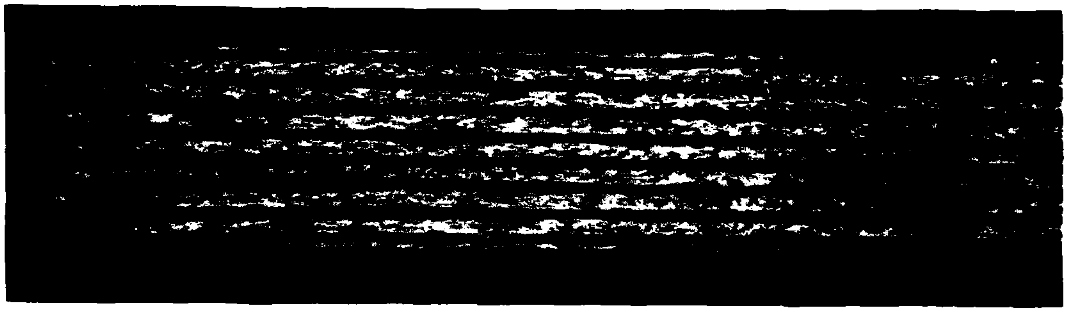
D19-5-1A 10x



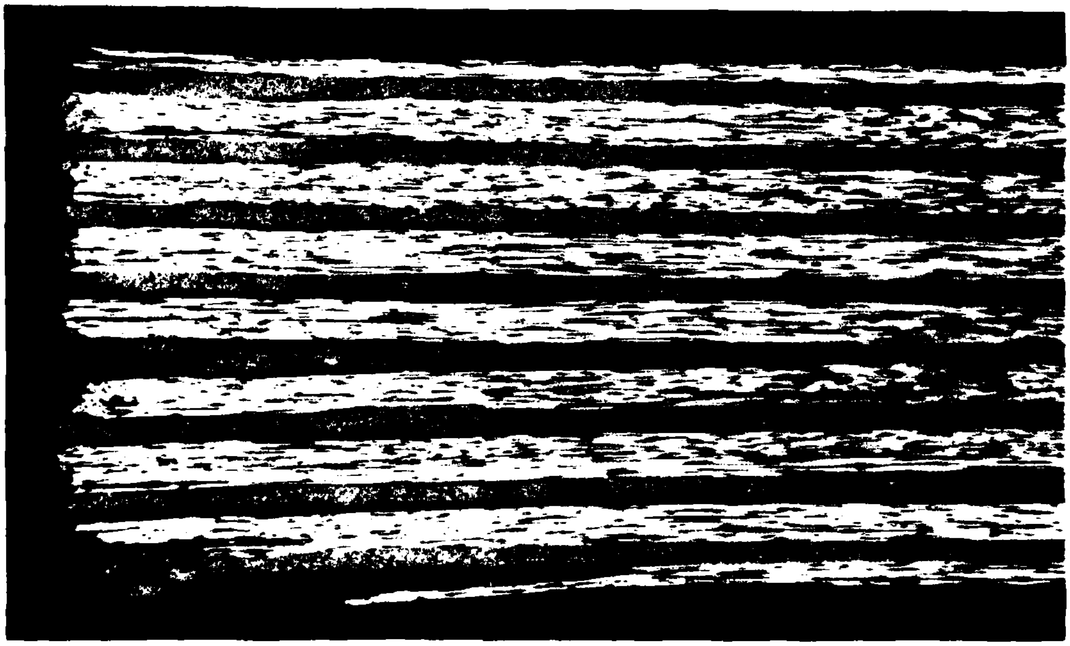
D19-5-2A 25x

LOCATION: 1.55 IN. DAMAGE LENGTH: 0.988 IN.

B-SCAN
@ 1.5 IN.



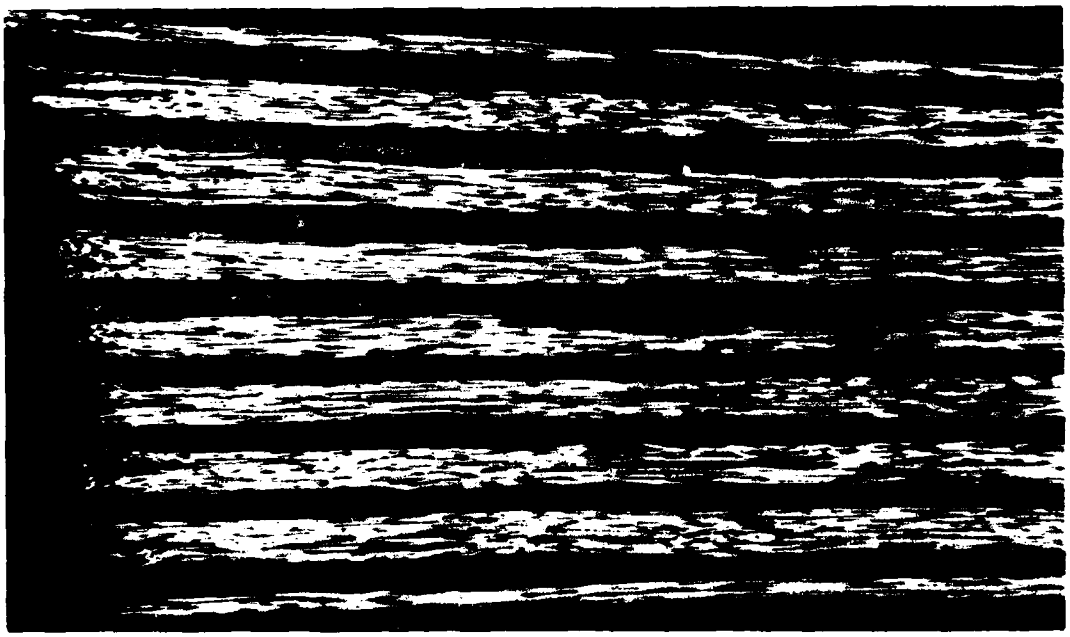
D19-5-1B 10x



D19-5-2B 25x

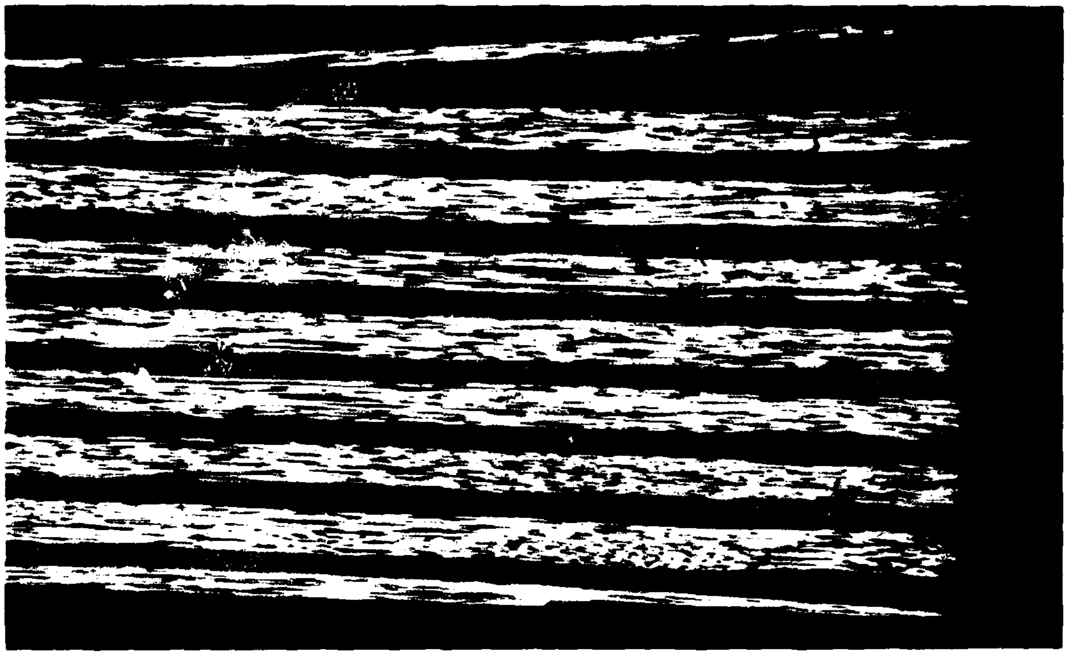
LOCATION: 1.55 IN. DAMAGE LENGTH 0.985 IN.


D19-6-1A 10X


D19-6-2A 25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.918

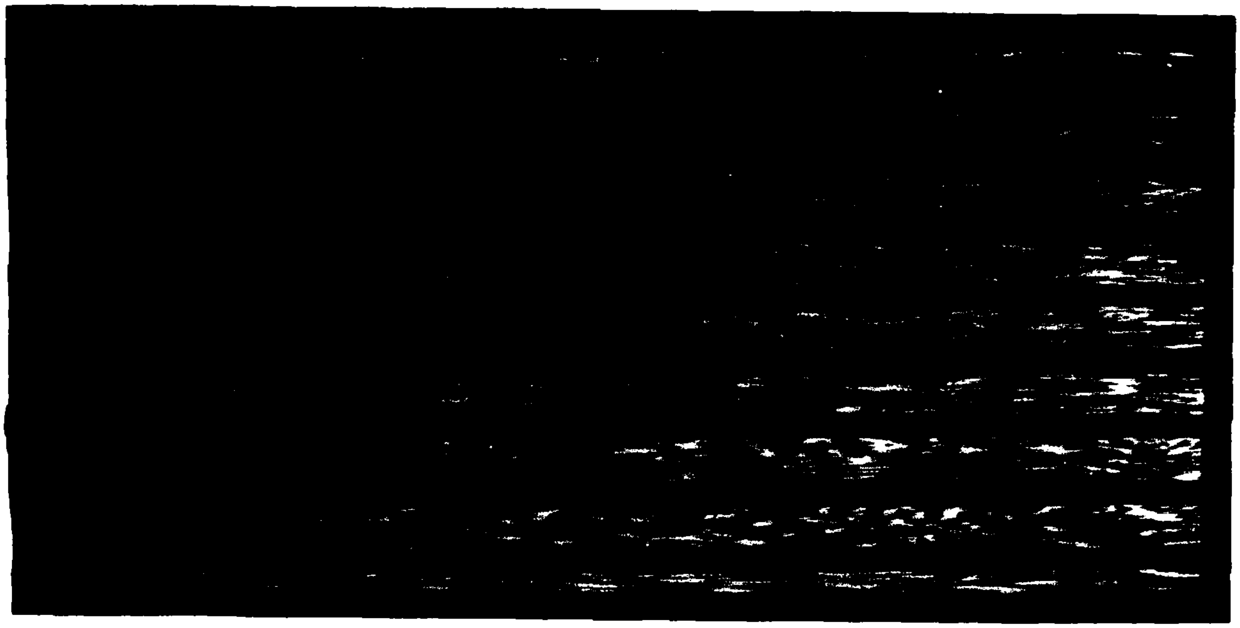
D19-6-1B 10X



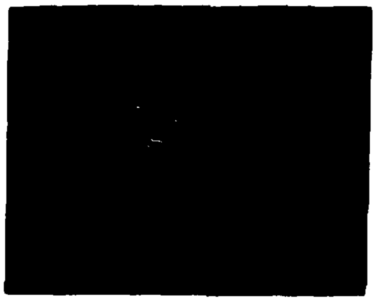
D-19-6-2B 25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.918

D19-7-1 10X



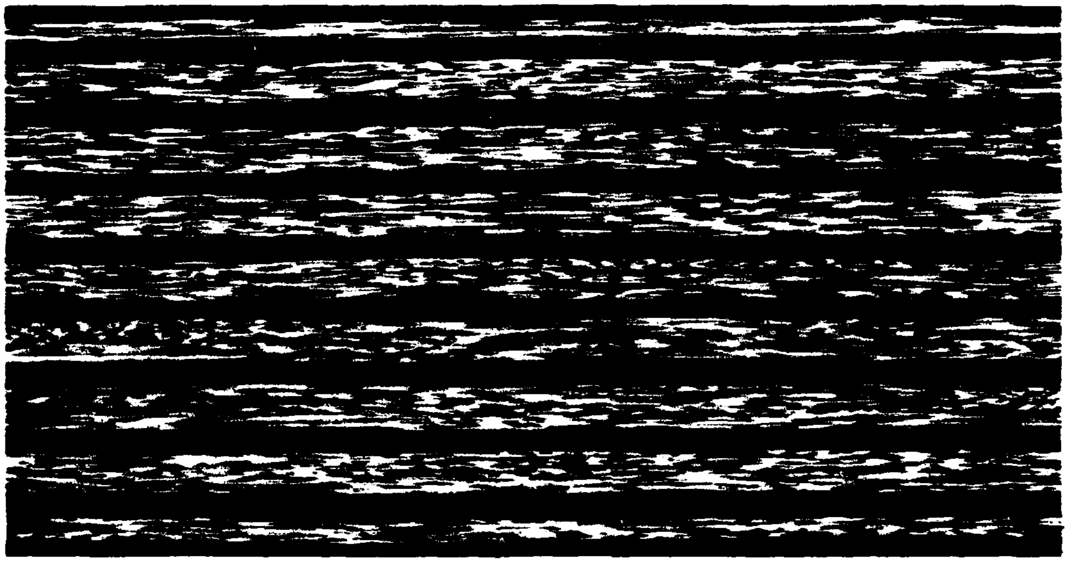
D19-7-2 25X



B-SCAN AT 1.78 IN.

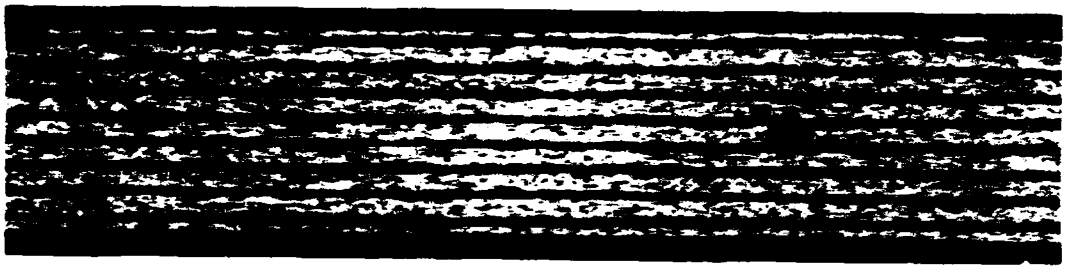
LOCATION: 1.75 IN. DAMAGE LENGTH: 0.710

D19-8-1 10X

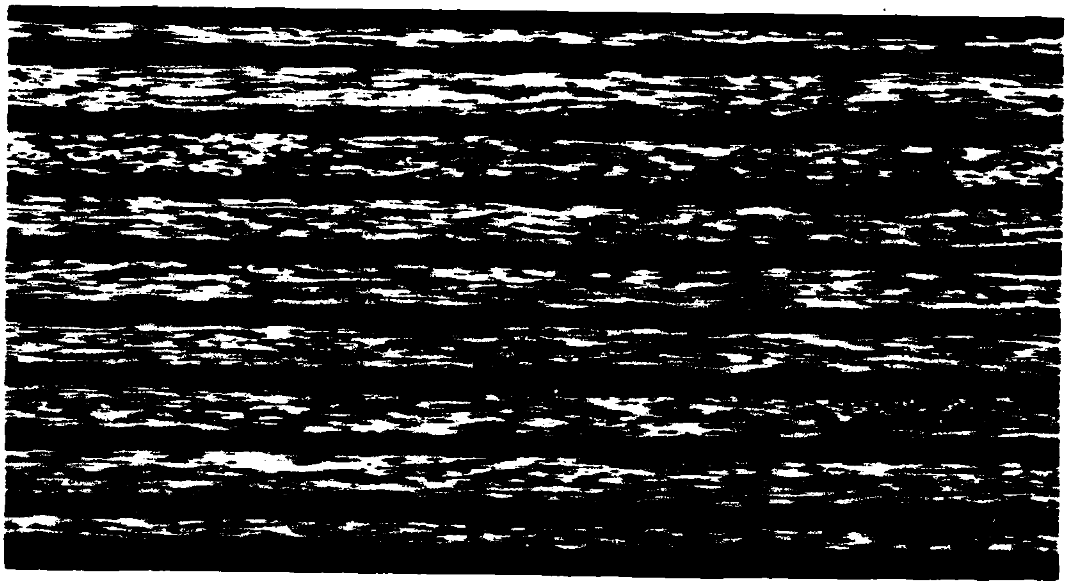


D-19-8-2 25X

LOCATION: 1.68 IN. DAMAGE LENGTH: 0.933

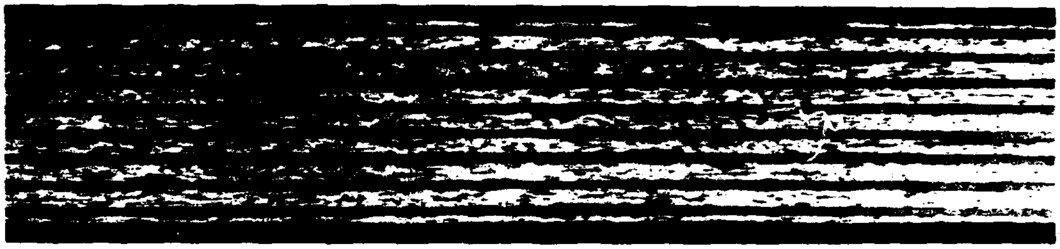


D19-9-1 10X



D-19-9-2 25X

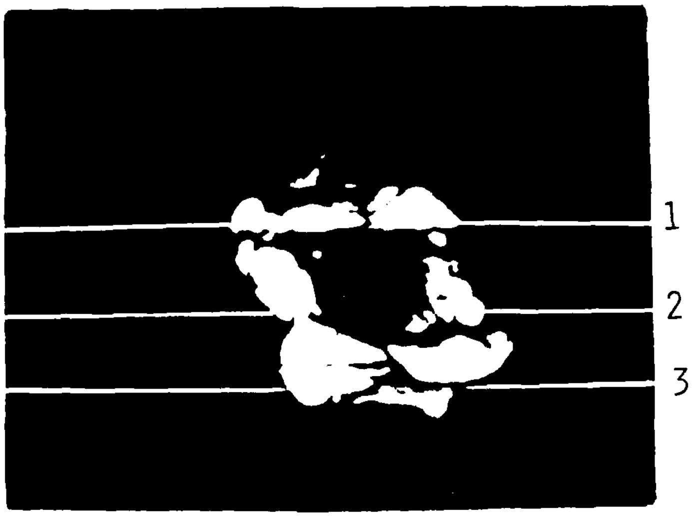
LOCATION: 1.78 IN. DAMAGE LENGTH: 0.888



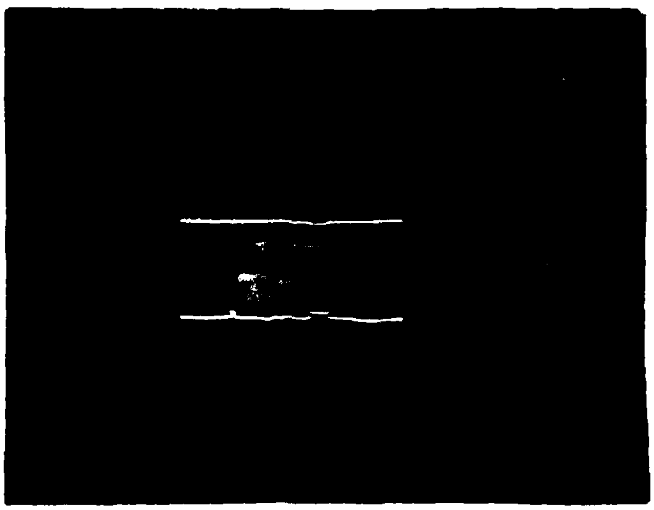
D19-10-1 10X

D-19-10-2 25X

LOCATION: 1.88 IN. DAMAGE LENGTH: 0.630

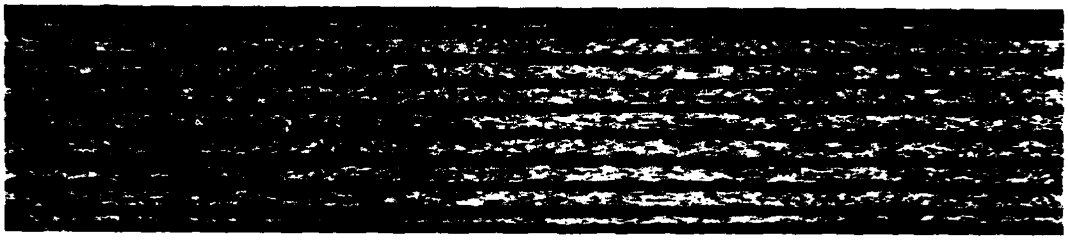


C-SCAN

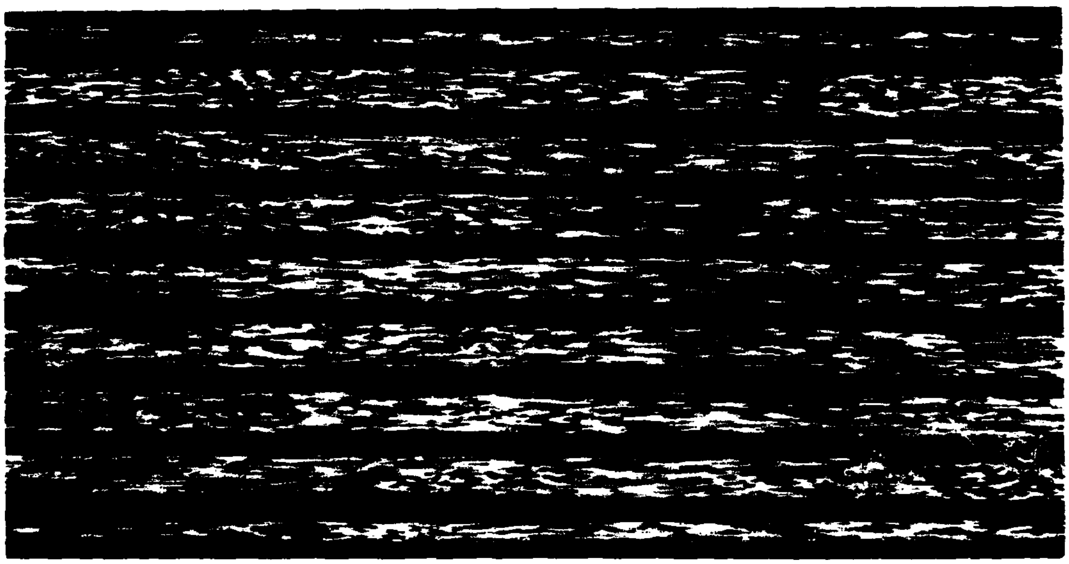


CUMULATIVE B-SCAN

24-PLY SPEC: IB-12 N_4 = 20,000 CYCLES



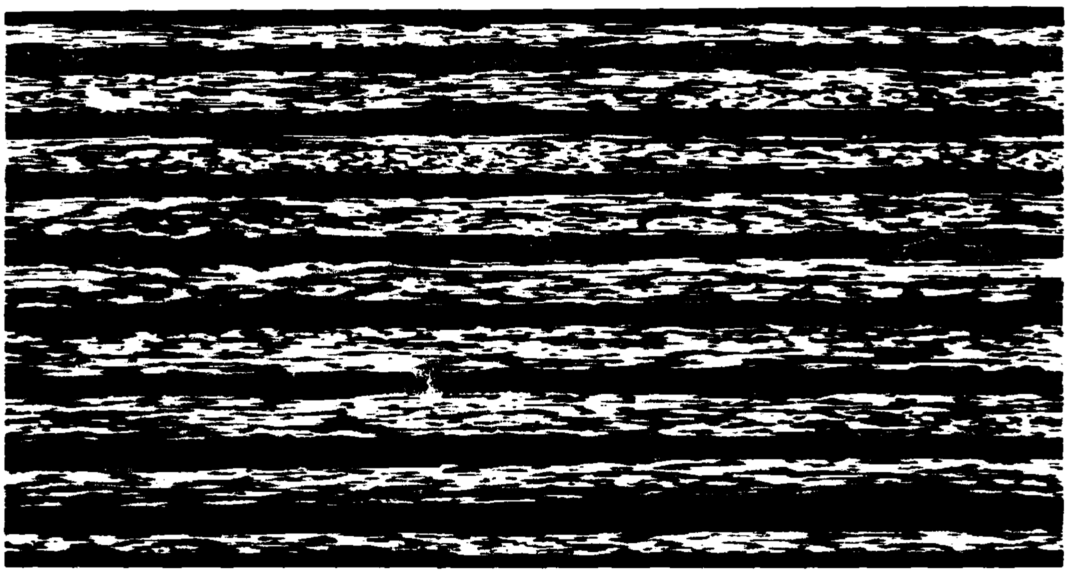
I12-1-1 10X



I12-1-2 25X

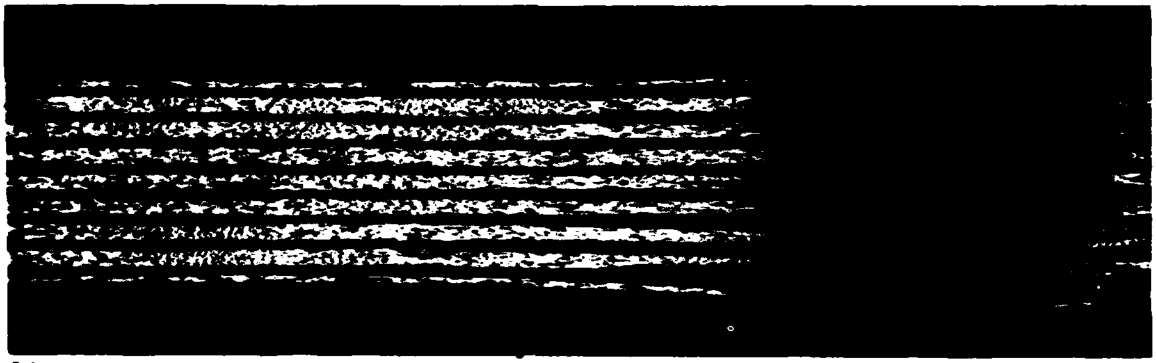
LOCATION: 1.08 IN. DAMAGE LENGTH: 0.439

I12-2-1 10X

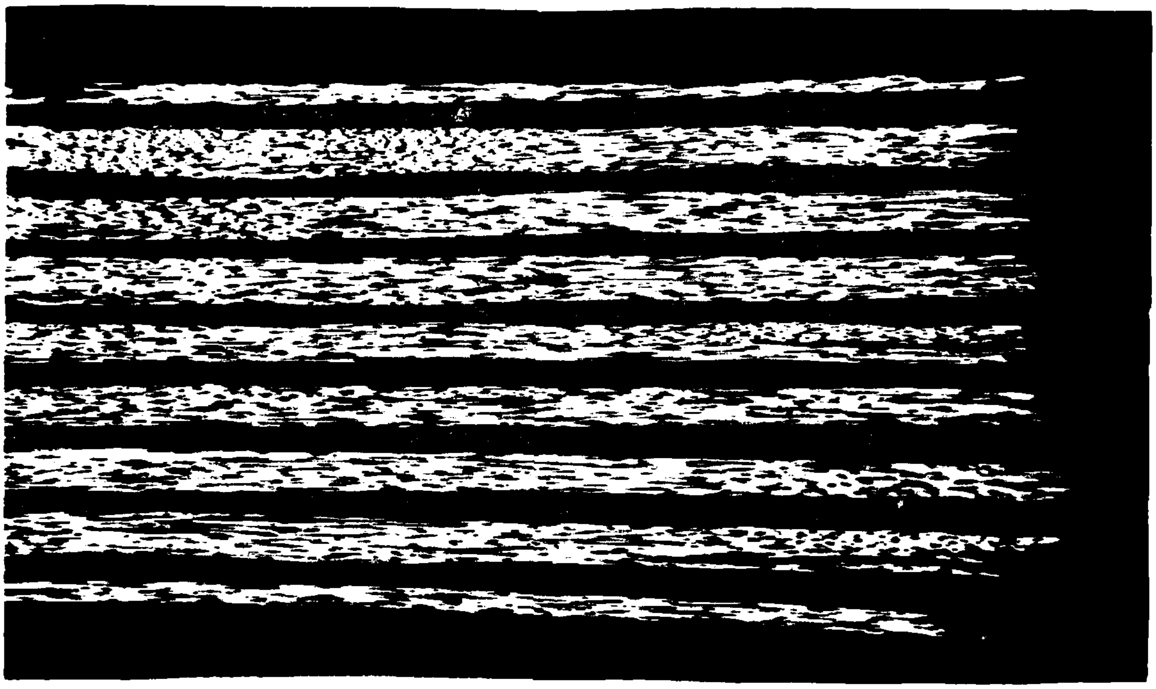


I12-2-2 25X

LOCATION: 1.22IN. DAMAGE LENGTH: 0.704



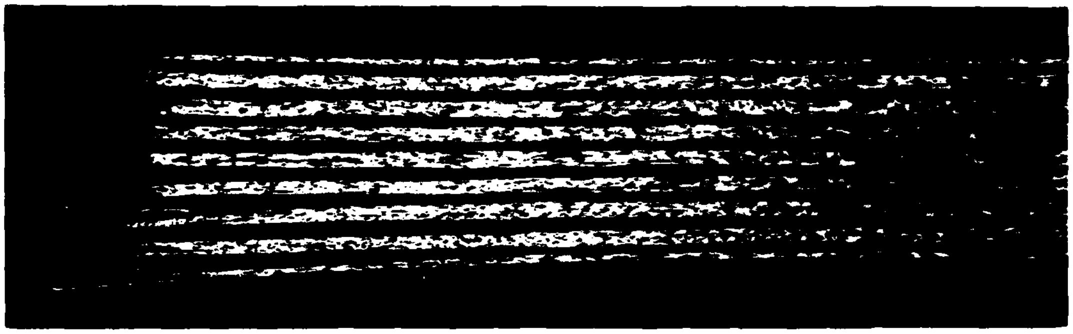
I12-3-1A 10X



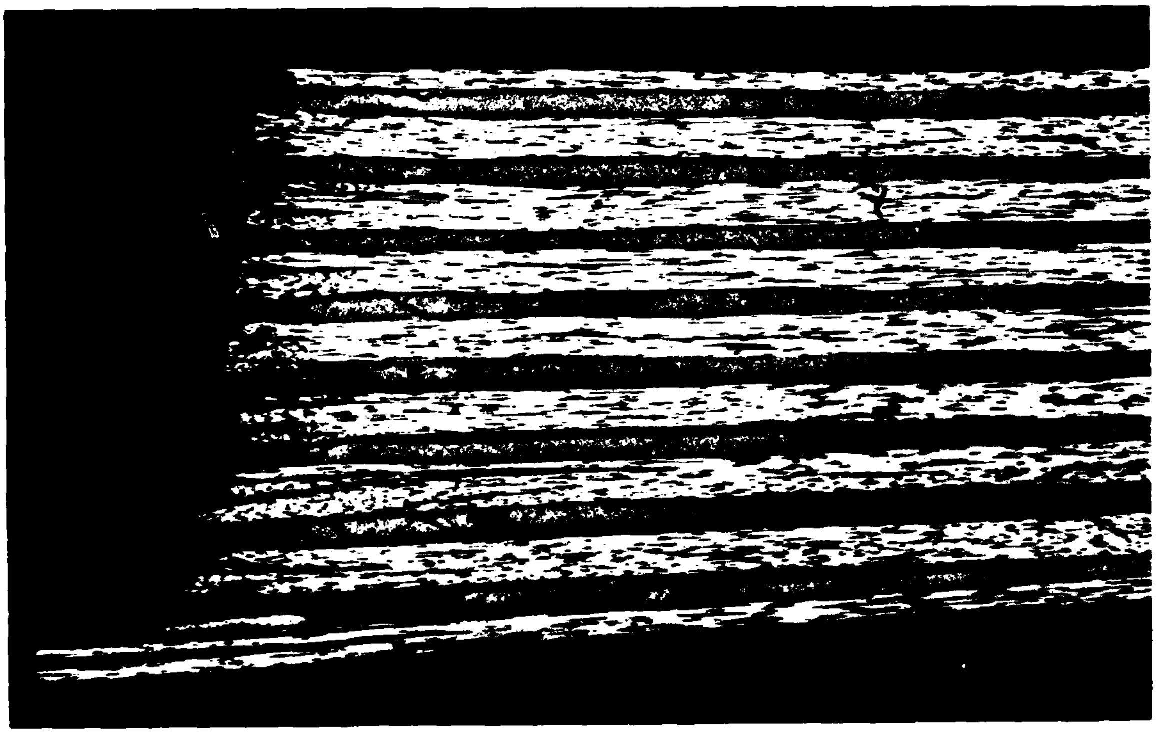
I12-3-2A 25X

B-SCAN AT 1.23 IN.

LOCATION: 1.28 IN. DAMAGE LENGTH: 0.868

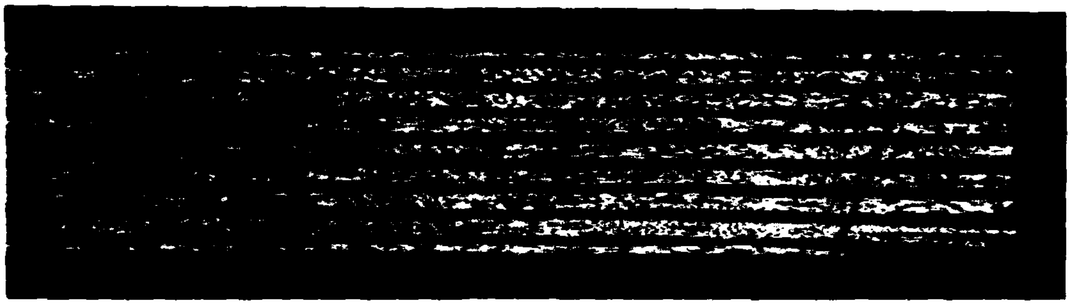


I12-3-1B 10X

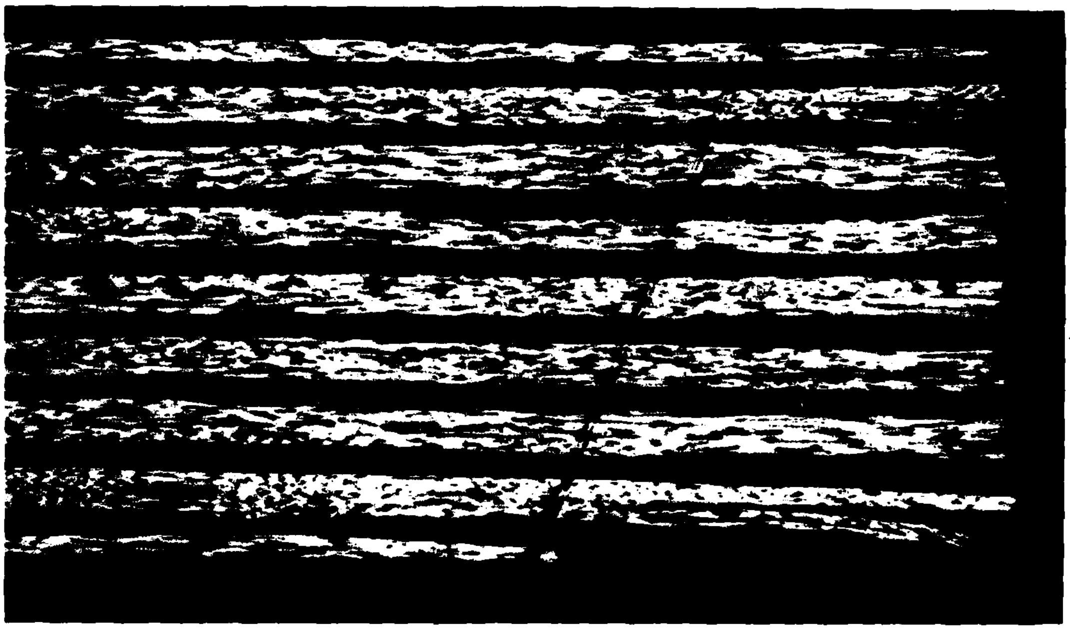


I12-3-2B 25X

LOCATION: 1.28 IN. DAMAGE LENGTH: 0.868

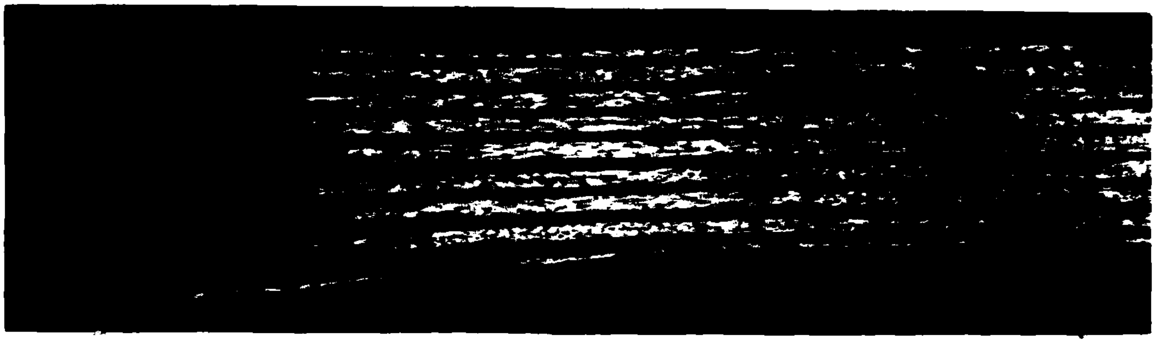


I12-4-1A 10X

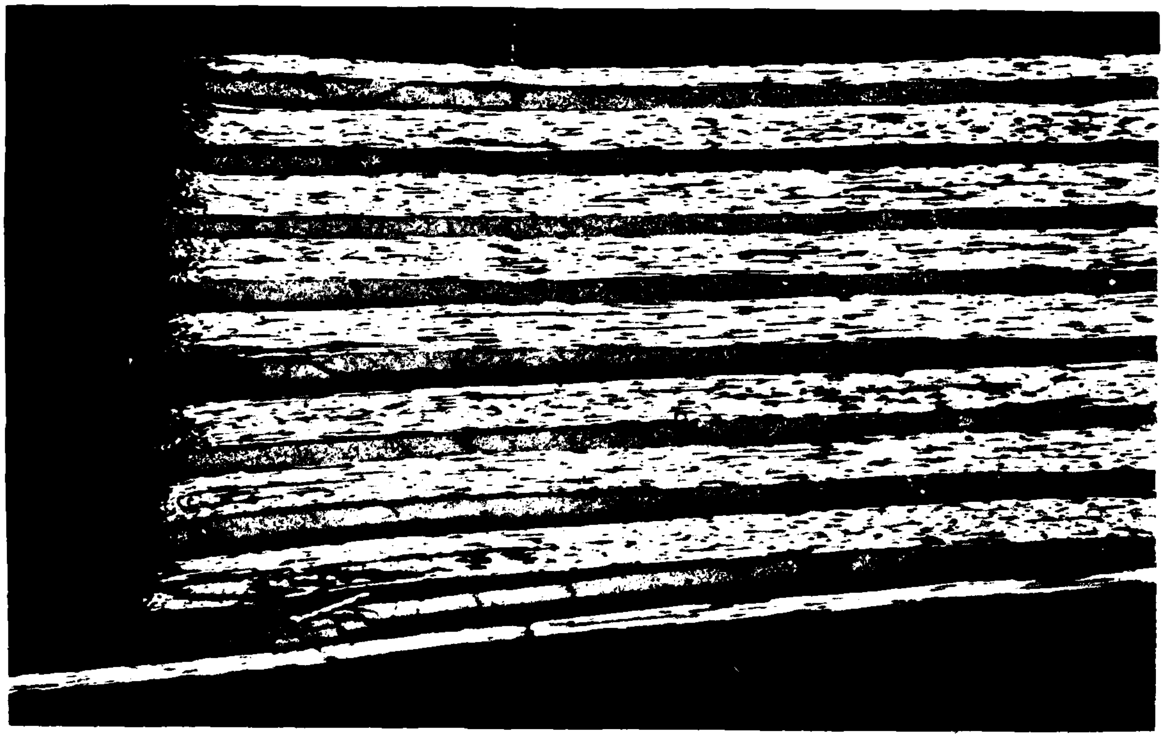


I12-4-2A 25X

LOCATION: 1.38 IN. DAMAGE LENGTH: 0.856

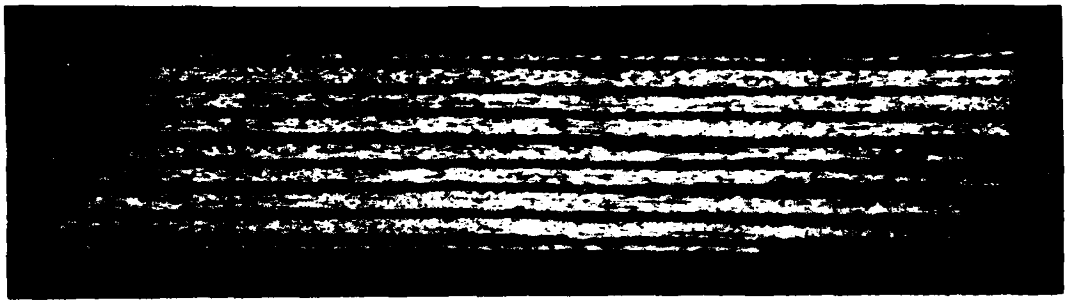


I12-4-1B 10X

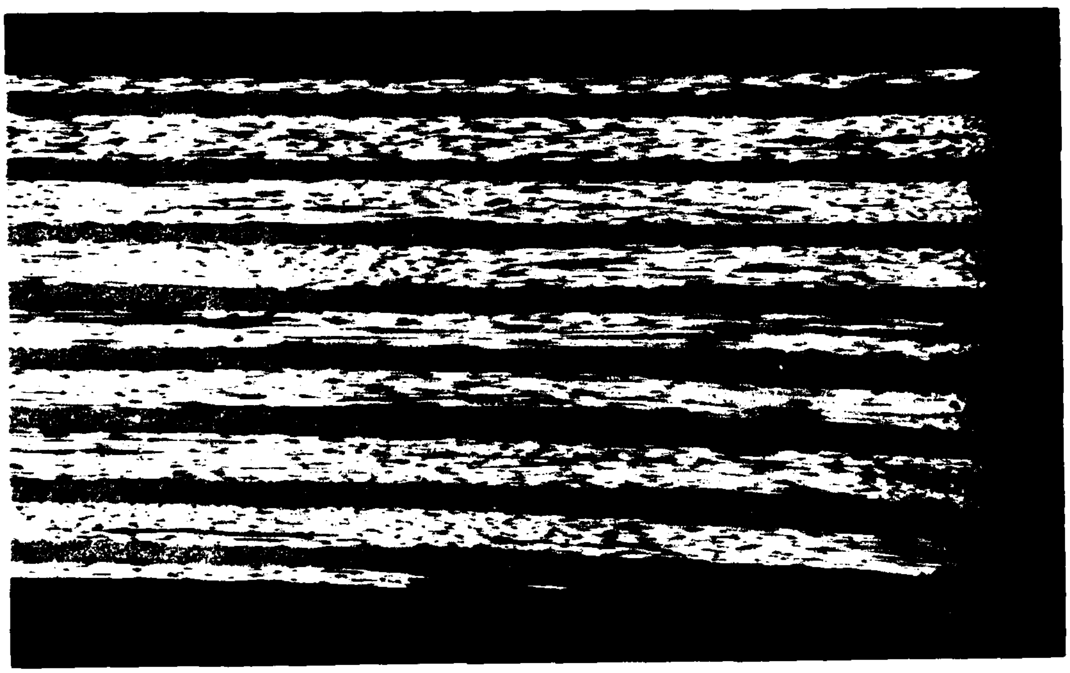


I12-4-2B 25X

LOCATION: 1.38 IN. DAMAGE LENGTH: 0.856



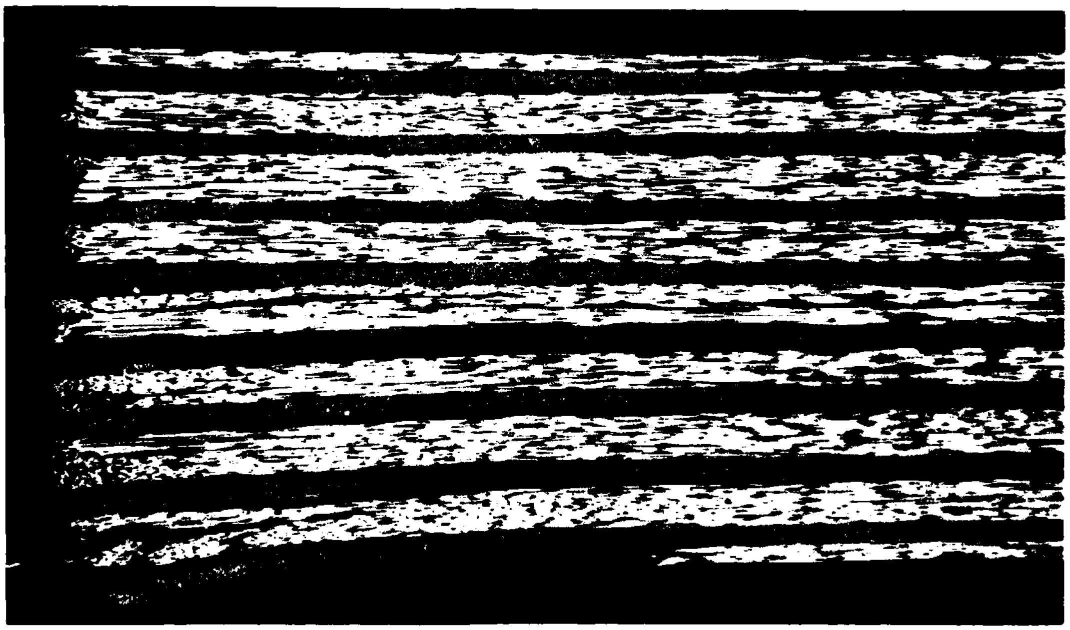
I12-5-1A 10X



I12-5-2A 25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.997

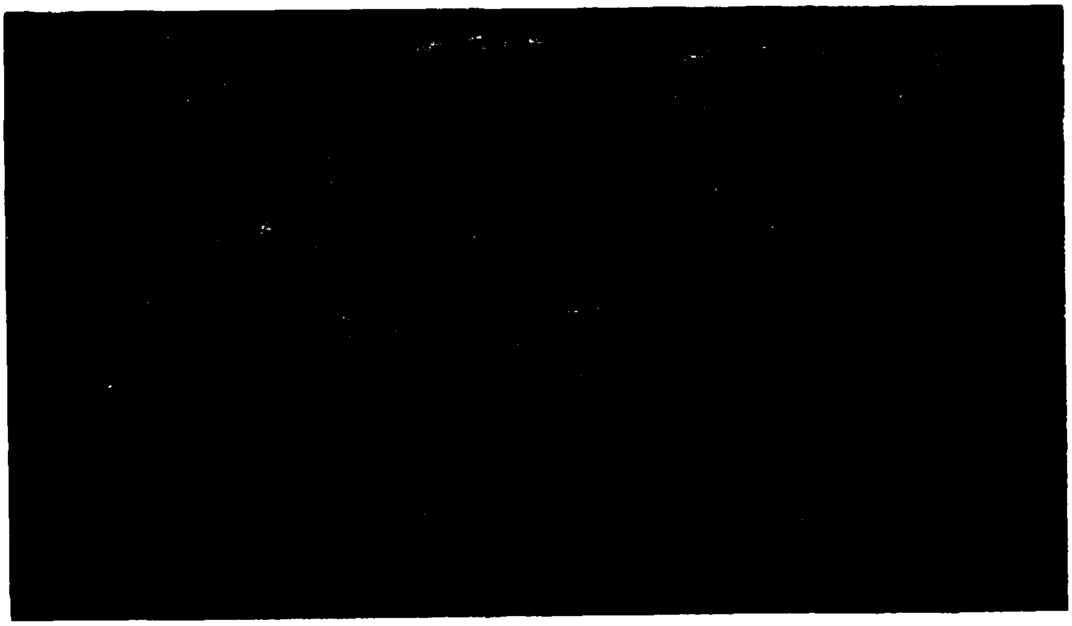
I12-5-1B 10X



I12-5-2B 25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.997

I12-6-1A 10X

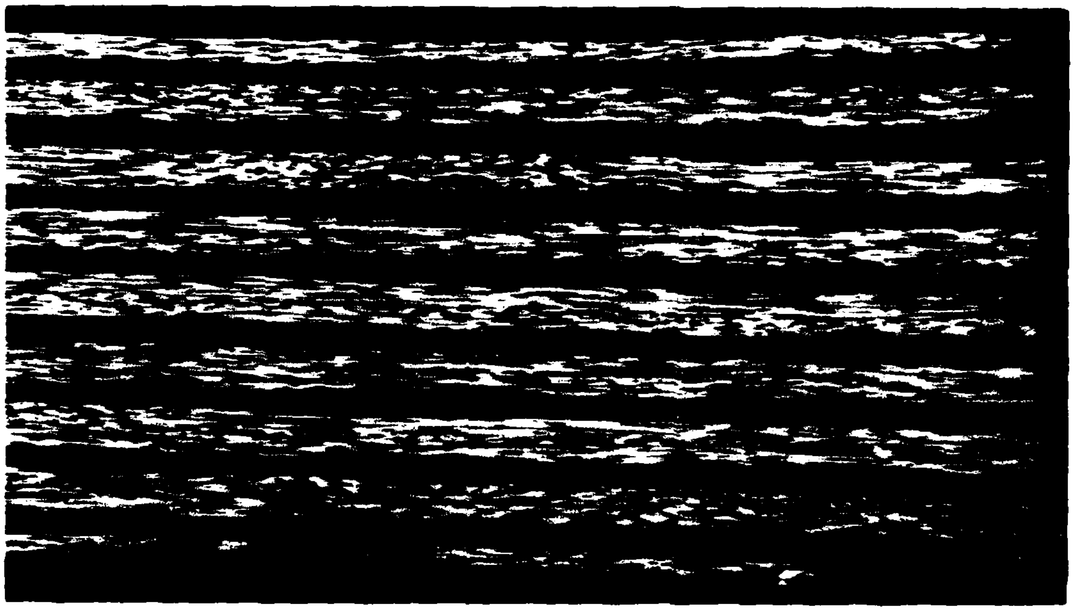


I12-6-2A 25X

LOCATION: 1.58 IN. DAMAGE LENGTH: 0.869

B-SCAN AT 1.59 IN.

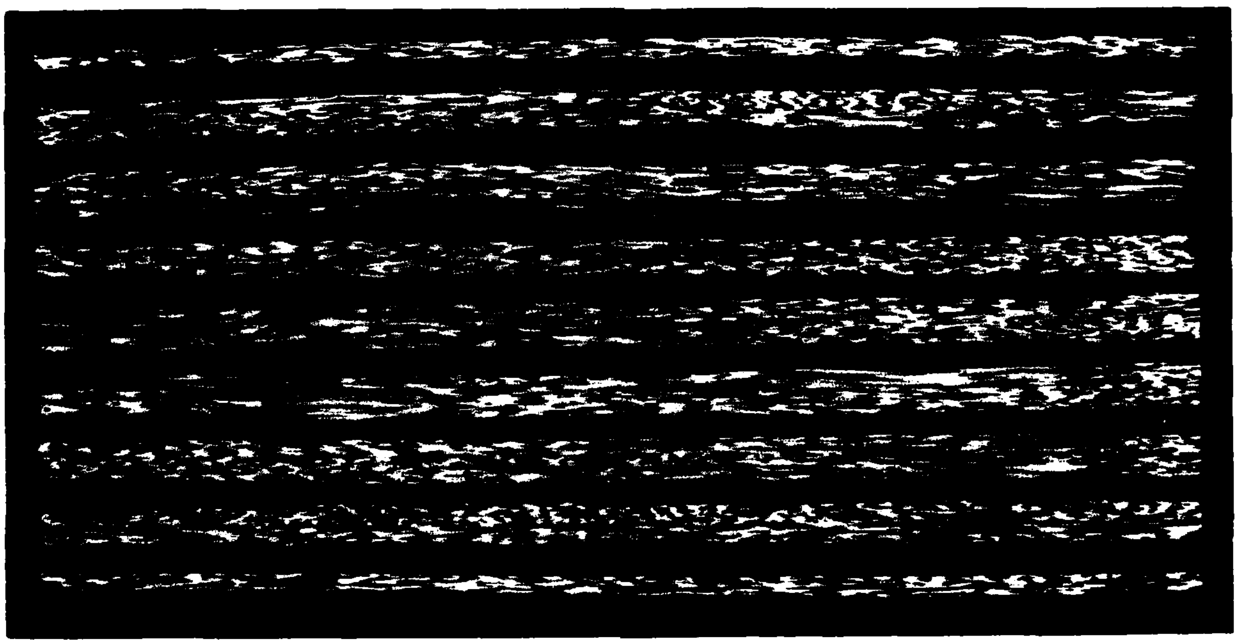
I12-6-1B 10X



I12-6-2B 25X

LOCATION: 1.58 IN. DAMAGE LENGTH: 0.869

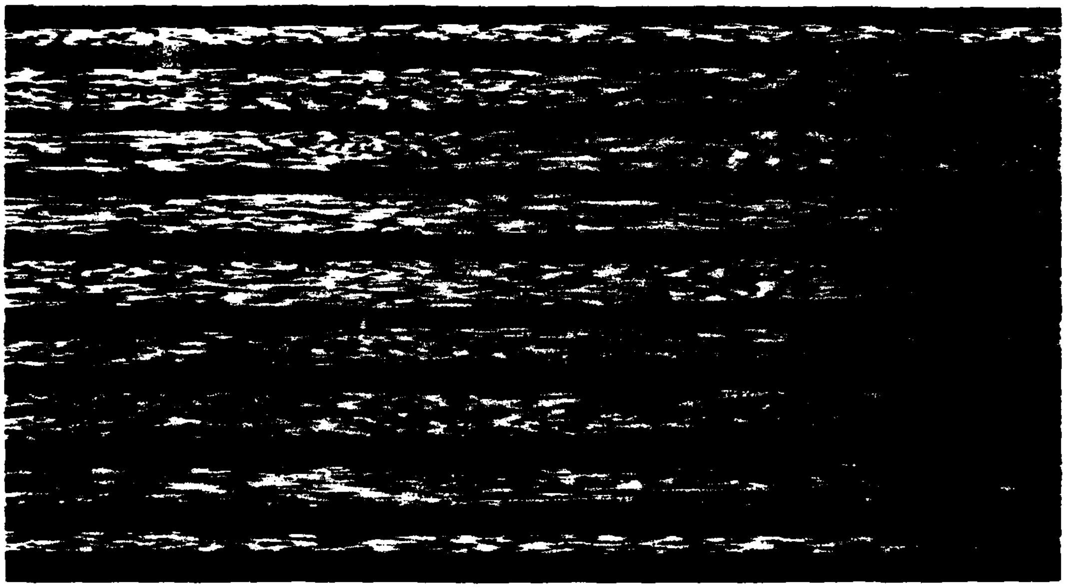
I12-7-1 10X



I12-7-2 25X

LOCATION: 1.68 IN. DAMAGE LENGTH: 0.973

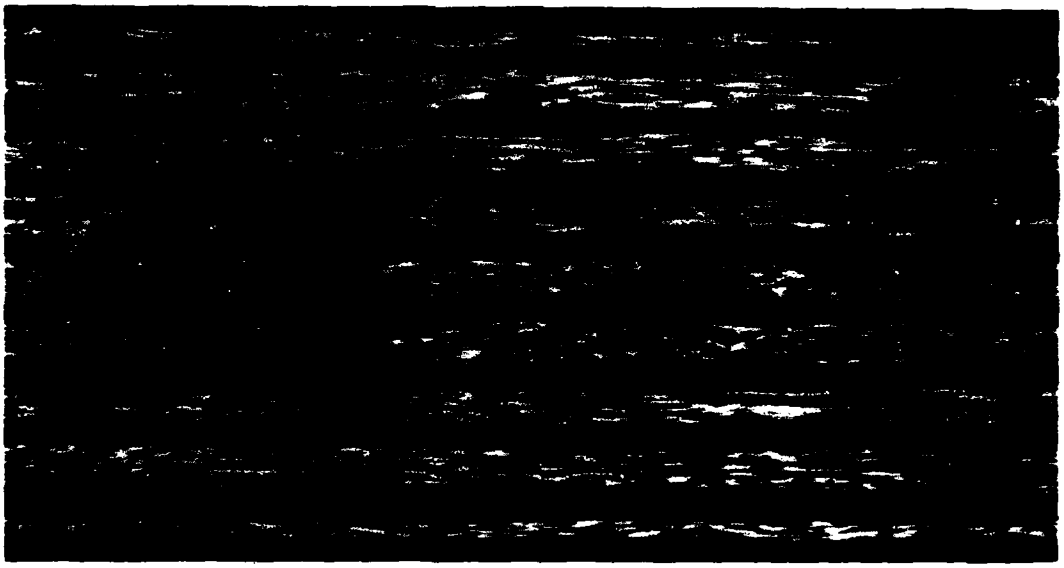
I12-8-1 10X



I12-8-2 25X

LOCATION: 1.78 IN. DAMAGE LENGTH: 0.907

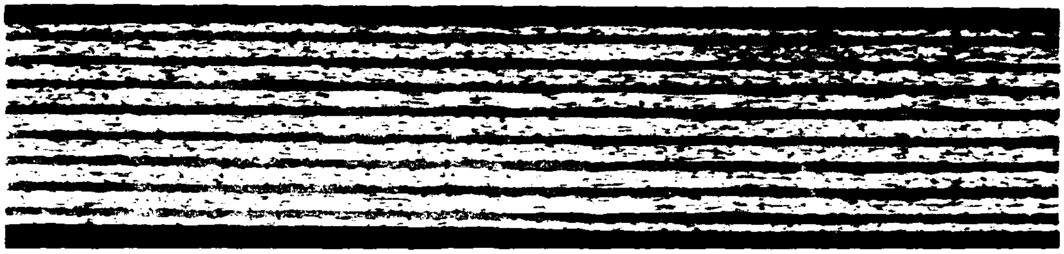
I12-9-1 10X



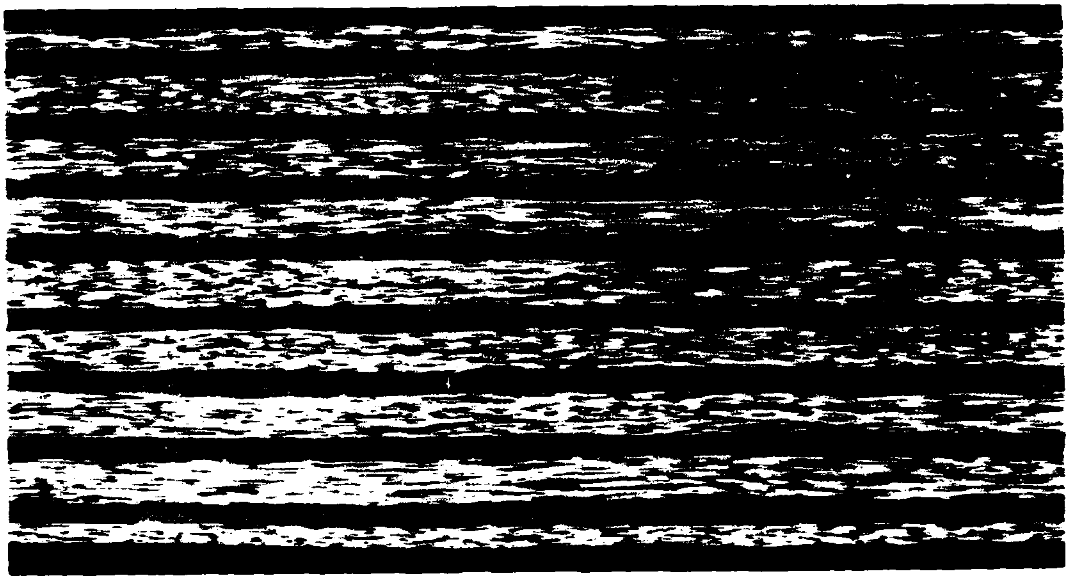
I12-9-2 25X

LOCATION: 1.88 IN. DAMAGE LENGTH: 0.702

B-SCAN AT 1.88 IN.



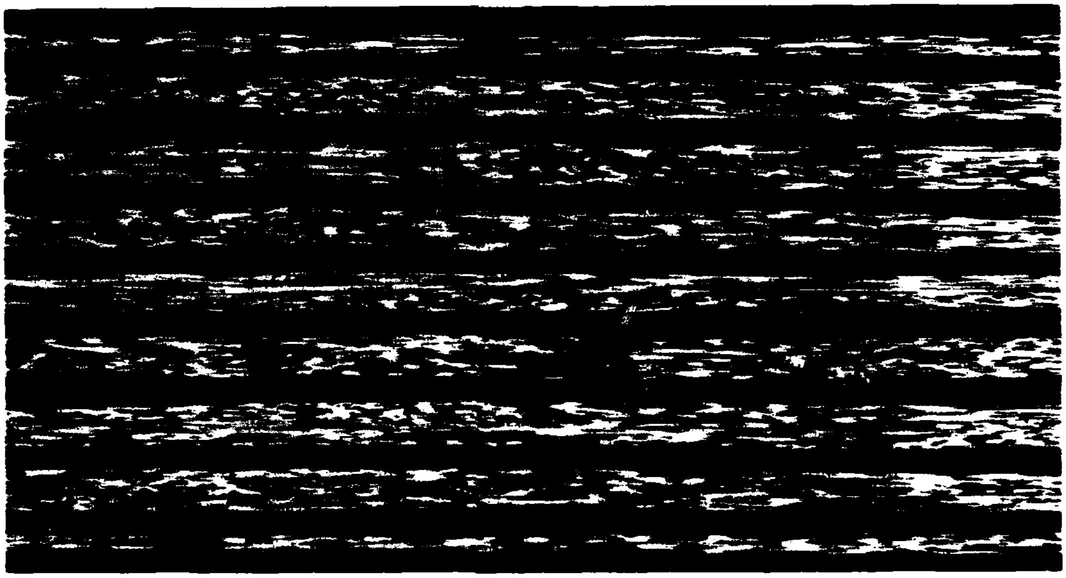
I12-10-1 10X



I12-10-2 25X

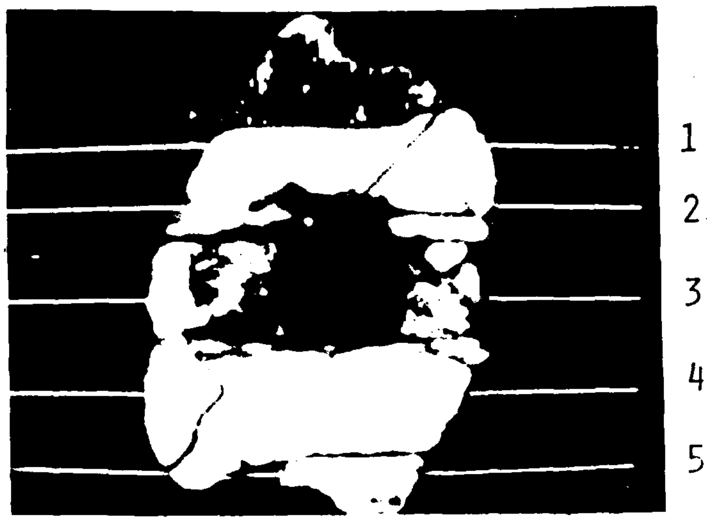
LOCATION: 1.98 IN. DAMAGE LENGTH: 0.204

I12-11-1 10X

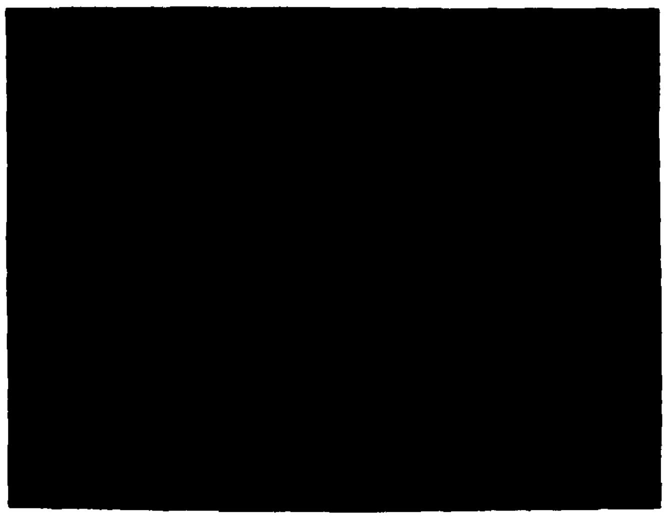


I12-11-2 25X

LOCATION: 2.08 IN. DAMAGE LENGTH: NO DAMAGE

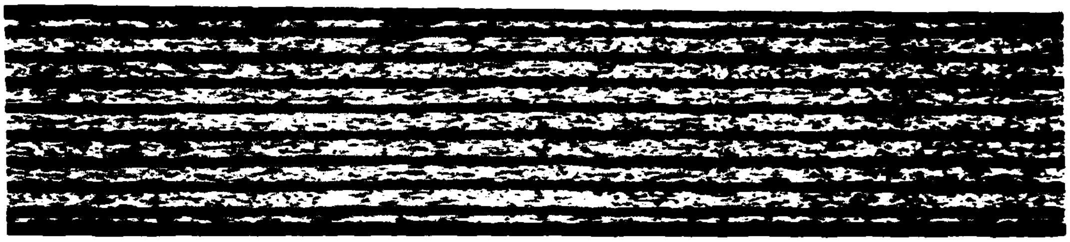


C-SCAN

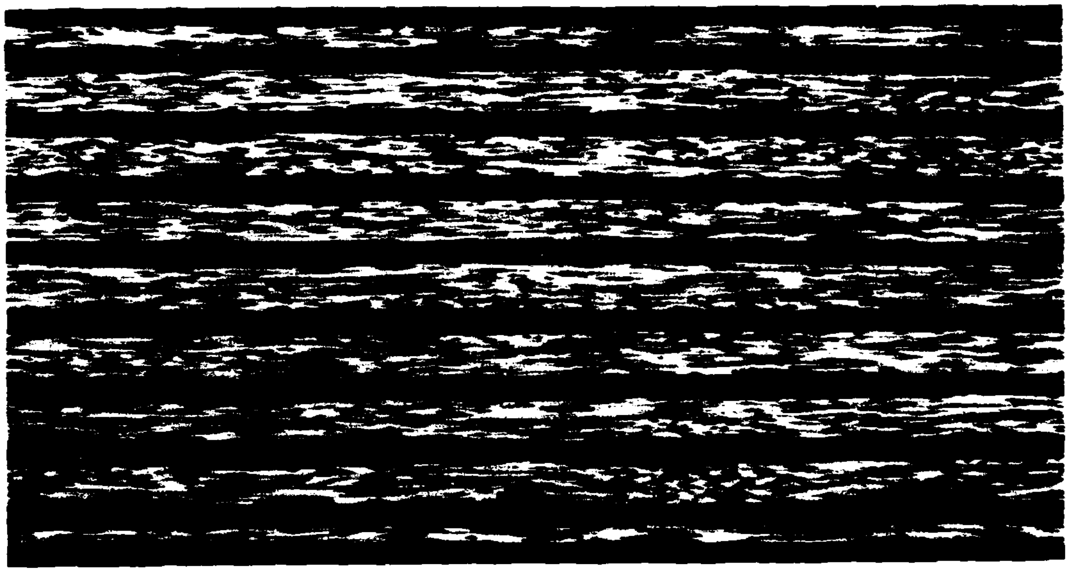


CUMULATIVE B-SCAN

24-PLY SPEC: EC-30 N_5 = 40,000



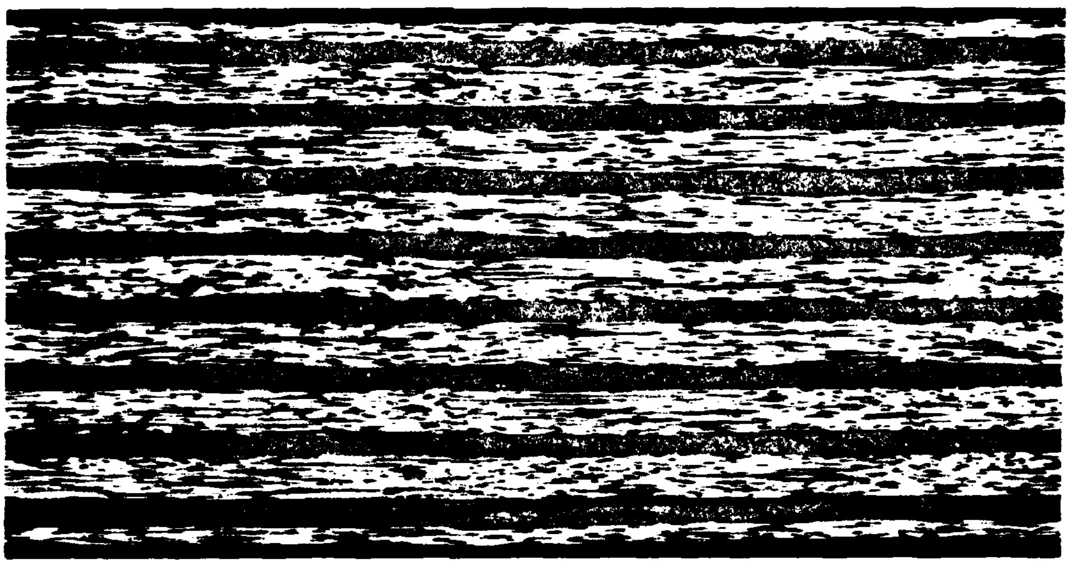
E30-1-1 10X



E30-1-2 25X

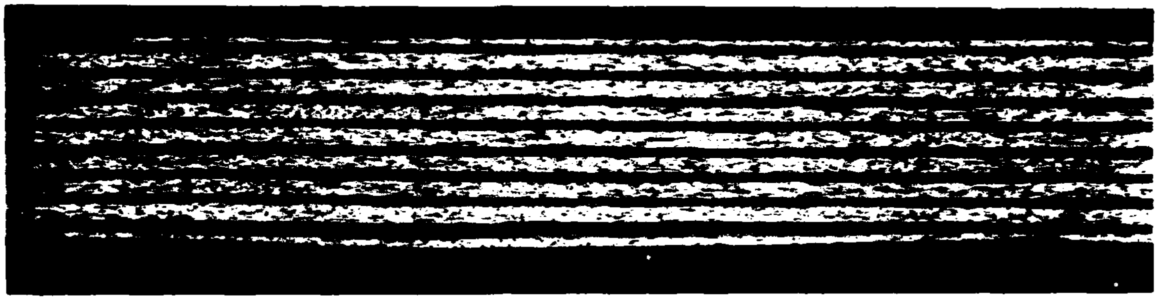
LOCATION: 0.45 IN. DAMAGE LENGTH: NO CRACKS

E30-2-1 10X

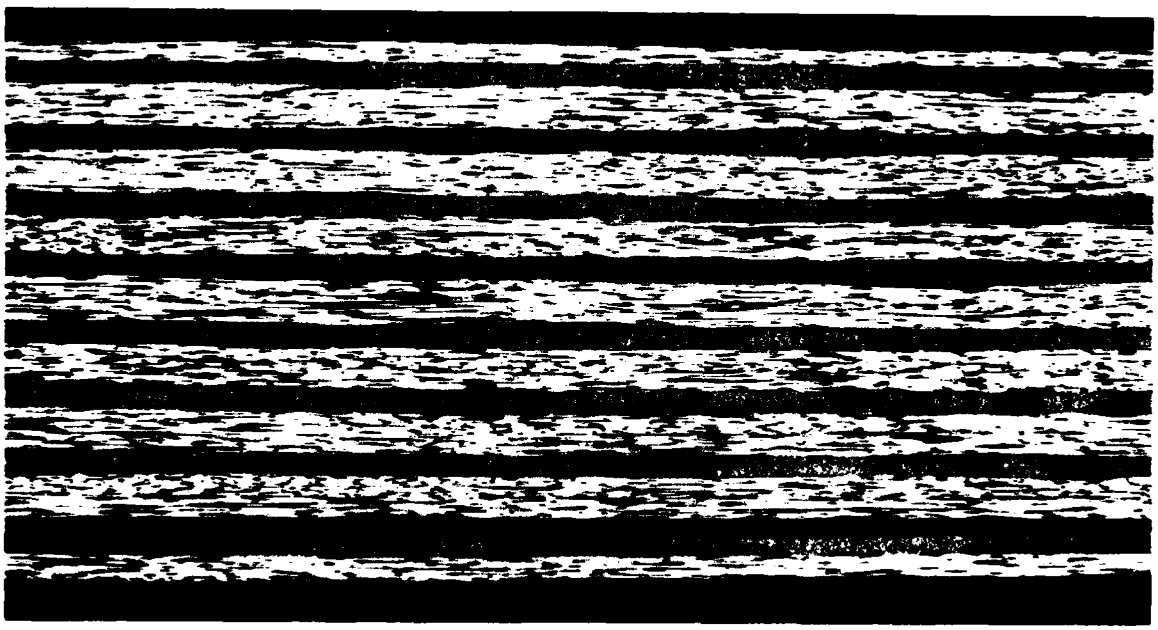


E30-2-2 25X

LOCATION: 0.55 IN. DAMAGE LENGTH: 0.326



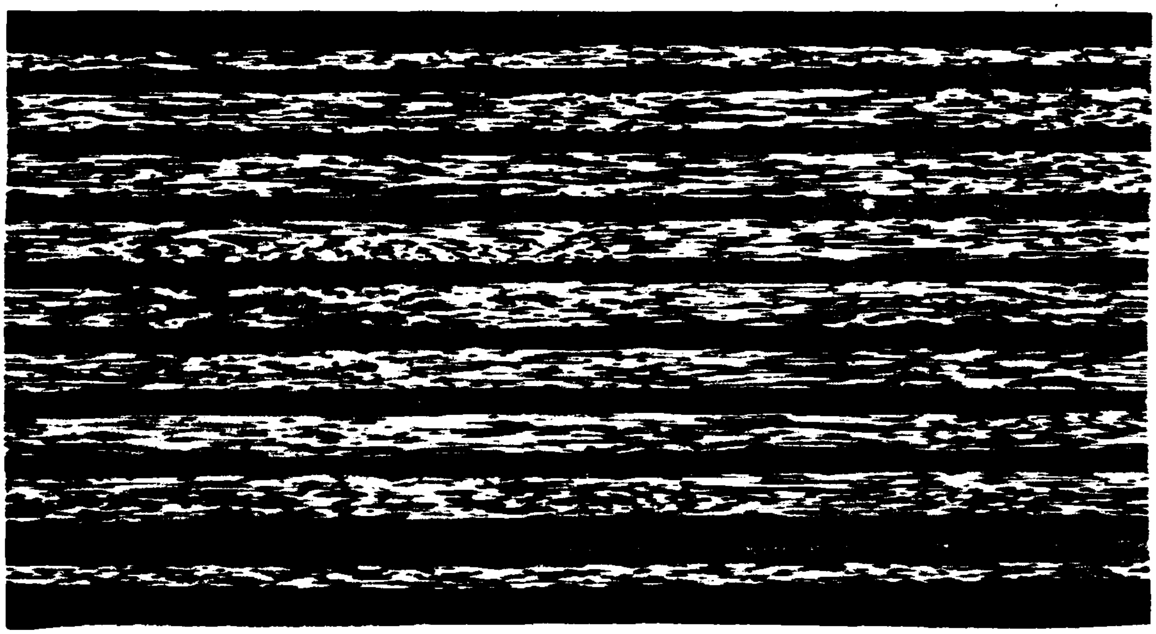
E30-3-1 10X



E30-3-2 25X

LOCATION 0.65 IN. DAMAGE LENGTH: 0.616

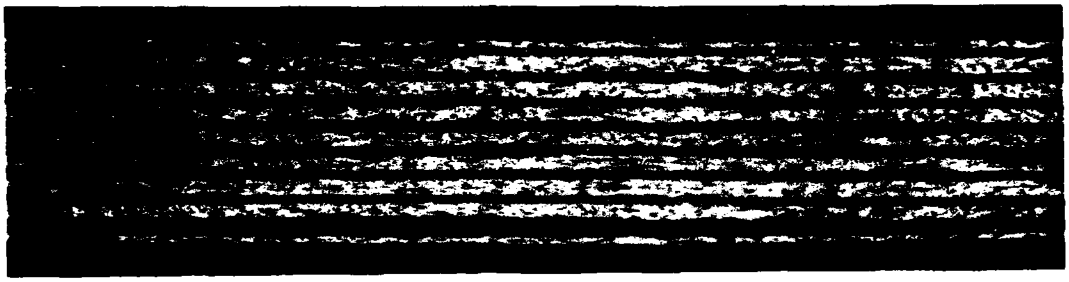
E30-4-1 10X



E30-4-2 25X

B-SCAN AT 1.79 IN.

LOCATION: 0.75 IN. DAMAGE LENGTH: 0.766

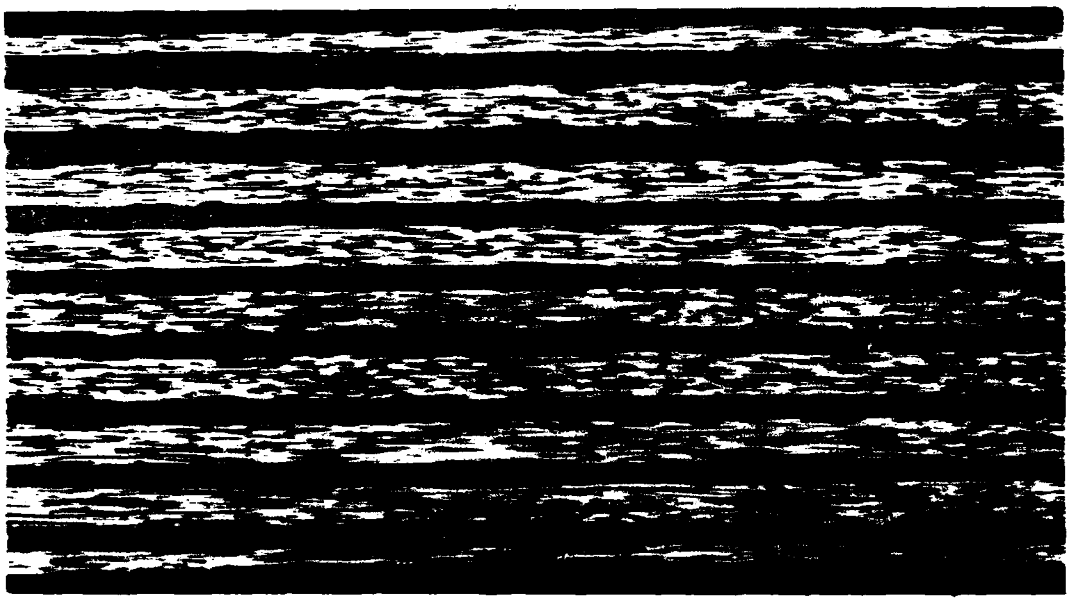


E30-5-1 10X

E30-5-2 25X

LOCATION: 0.85 IN. DAMAGE LENGTH: 0.822

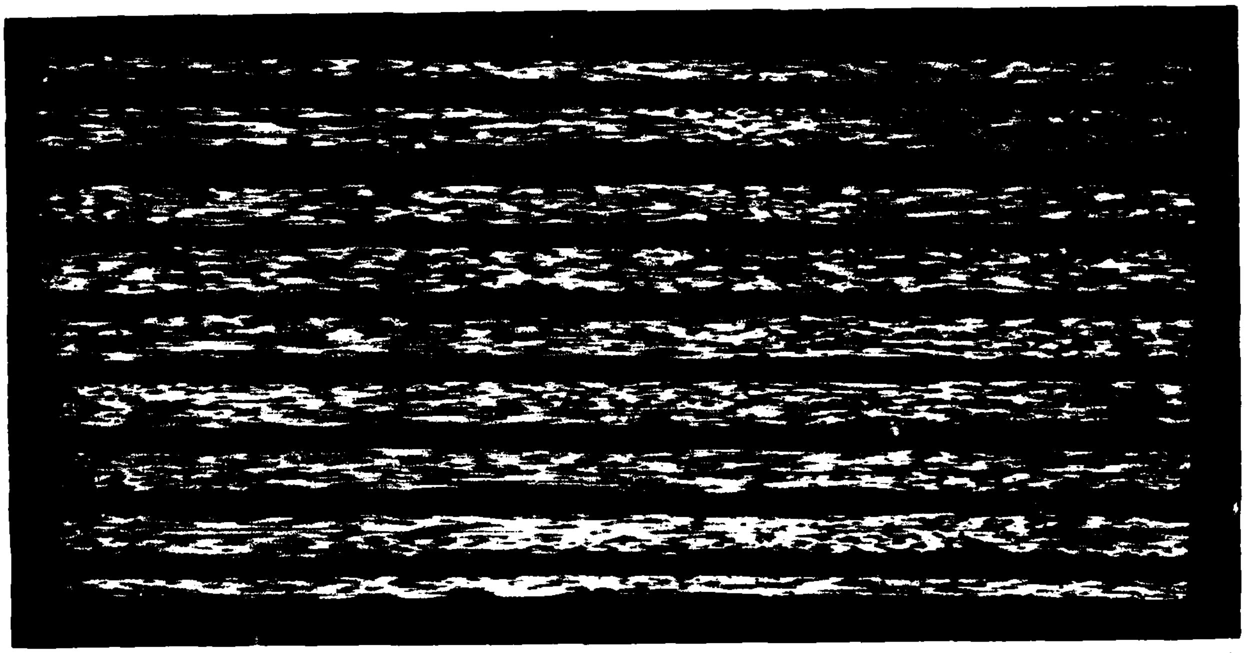
E30-6-1 10X



E30-6-2 25X

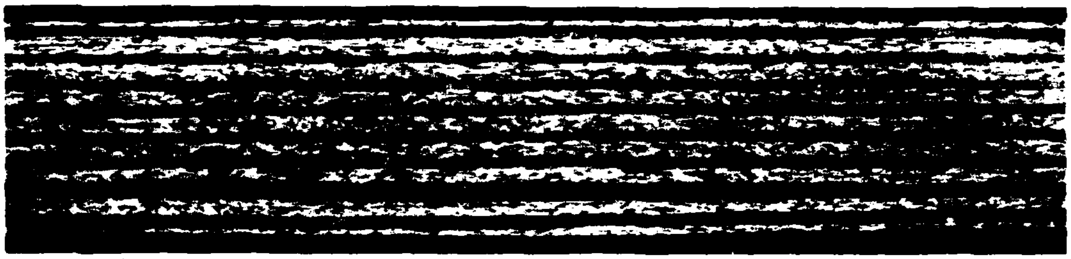
LOCATION: 0.95 IN. DAMAGE LENGTH: 0.957

E30-7-1 10X

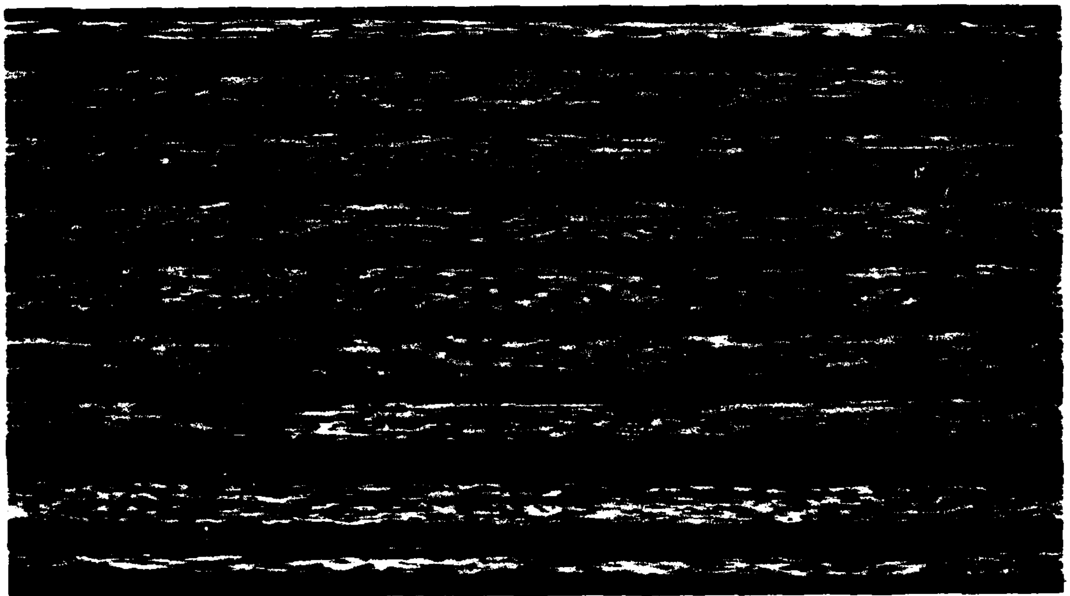


E30-7-2 25X

LOCATION: 1.05 IN. DAMAGE LENGTH: 1.192

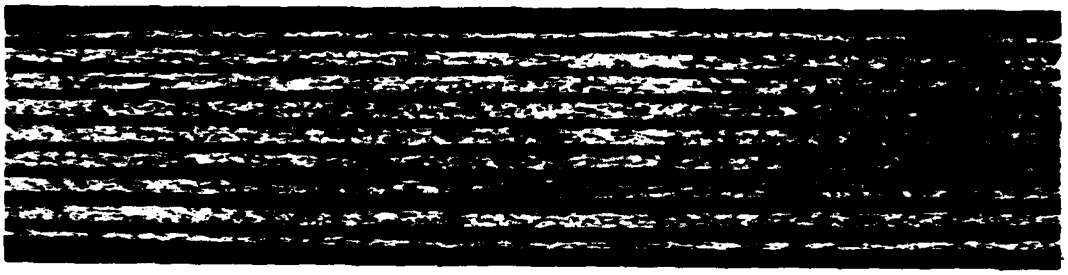


E30-8-1 10X



E30-8-2 25X

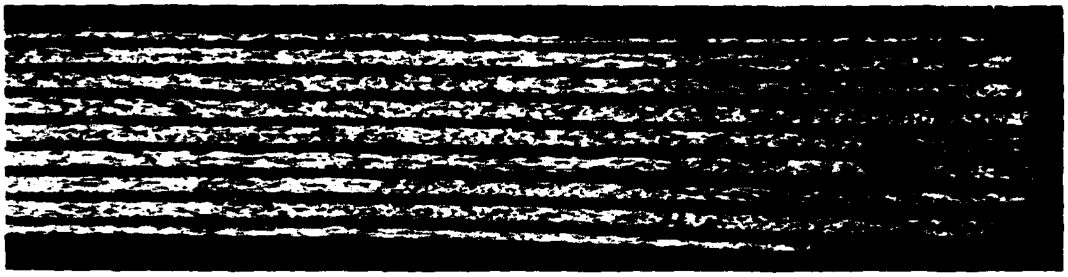
LOCATION: 1.15 IN. DAMAGE LENGTH: 1.138



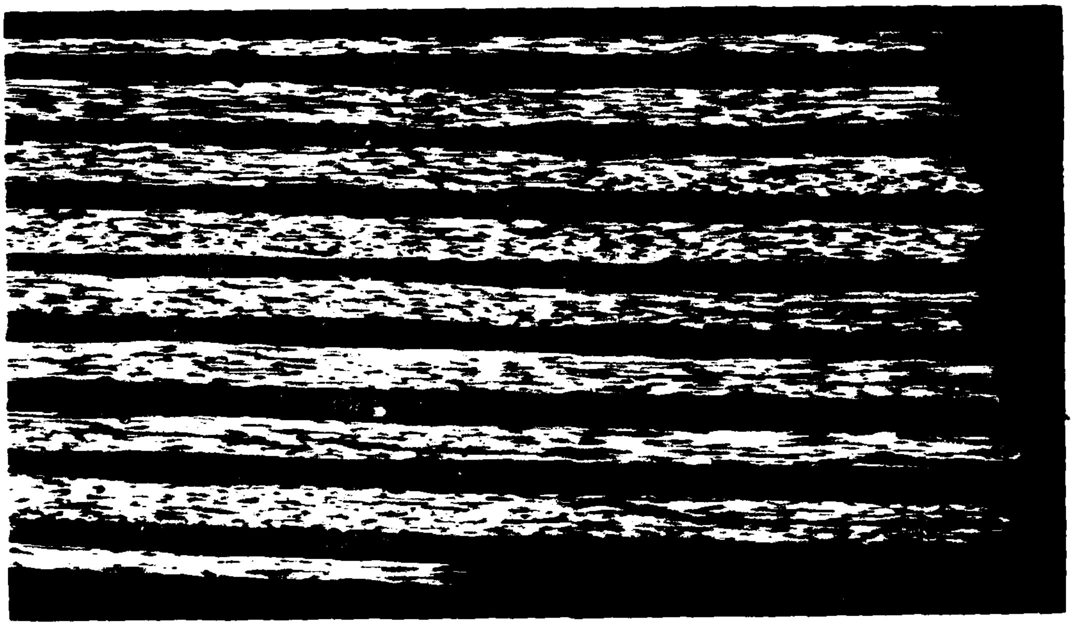
E30-9-1 10X

E30-9-2 25X

LOCATION: 1.25 IN. DAMAGE LENGTH: 1.259

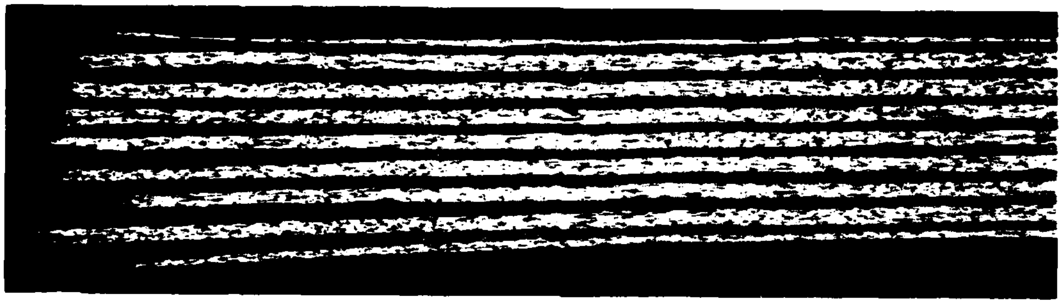


E30-10-1A 10X

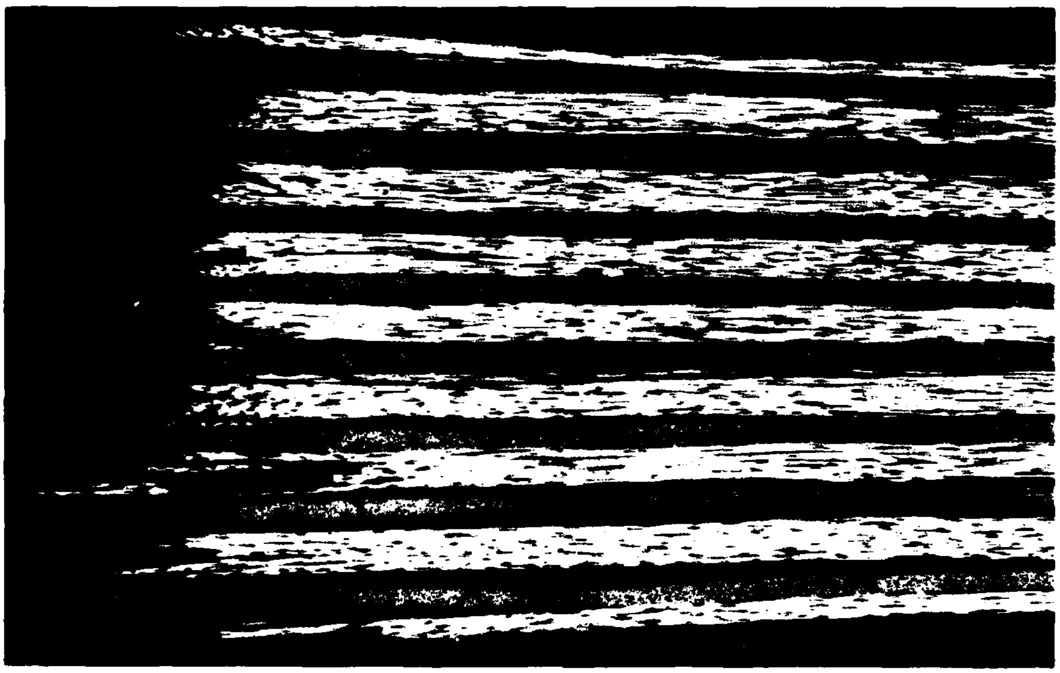


E30-10-1A 25X

LOCATION: 1.35 IN. DAMAGE LENGTH: 1.200

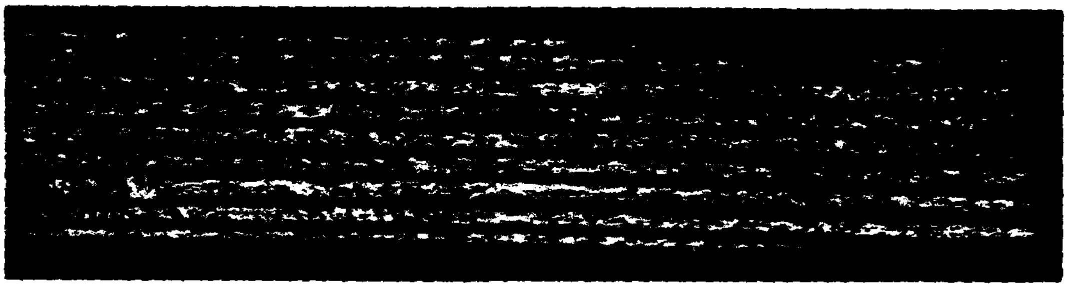


E30-10-1B 10X

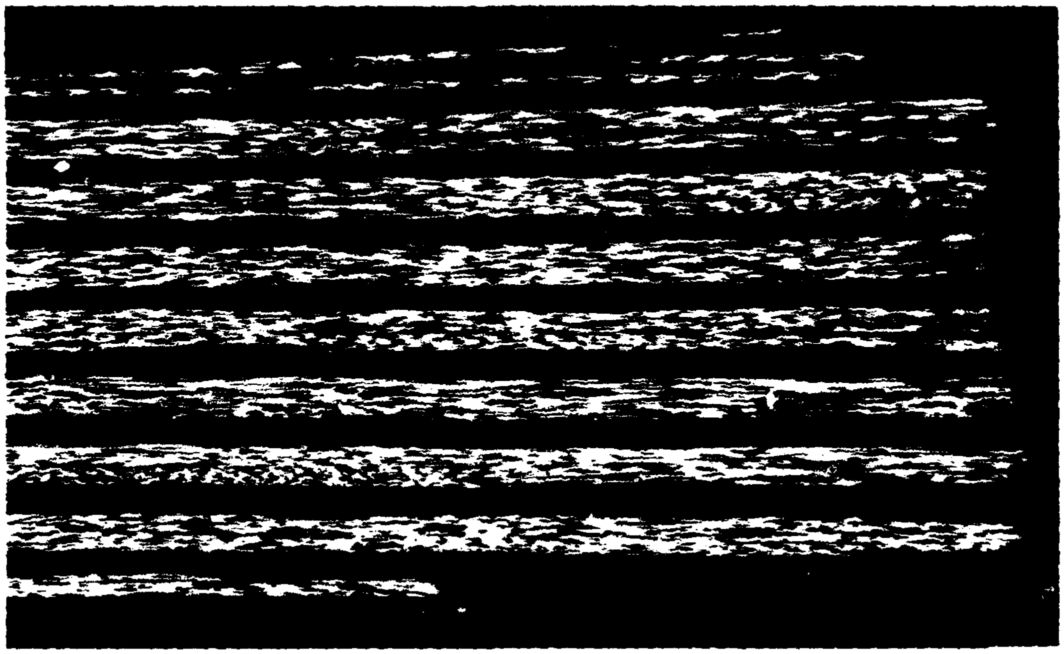


E30-10-2B 25X

LOCATION: 1.35 IN. DAMAGE LENGTH: 1.200

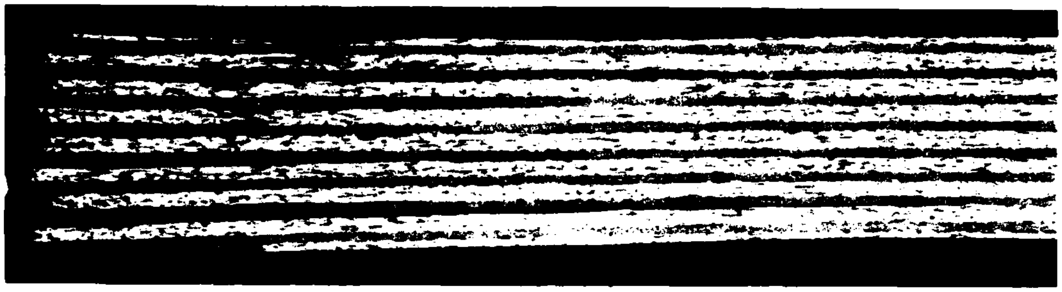


E30-11-1A 10X

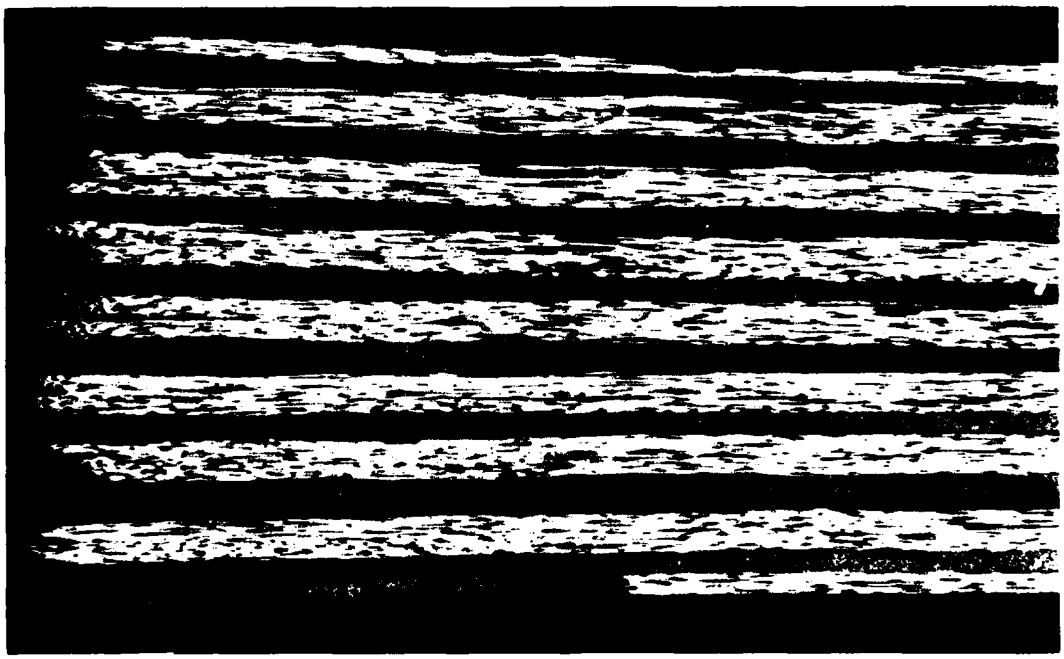


E30-11-2A 25X

LOCATION: 1.45 IN. DAMAGE LENGTH: 1.277



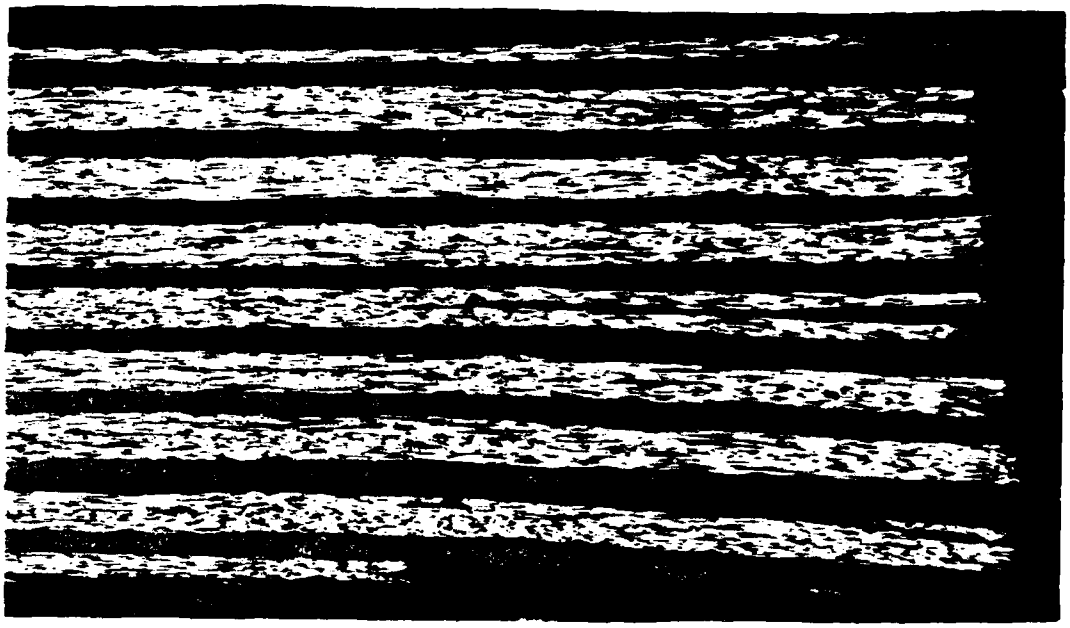
E30-11-1B 10X



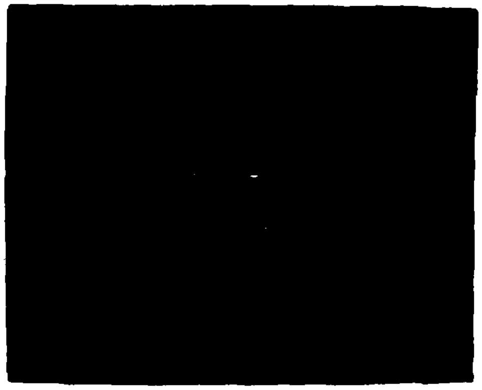
E30-11-2B 25X

LOCATION: 1.45 IN. DAMAGE LENGTH: 1.277

E3C-12-1A 10X

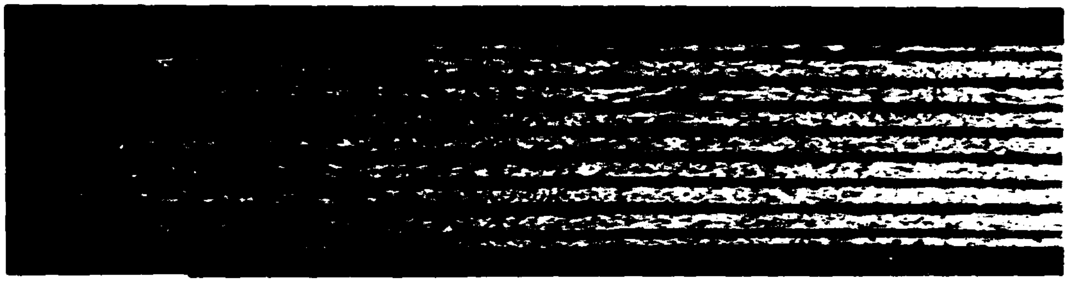


E30-12-1A 25X

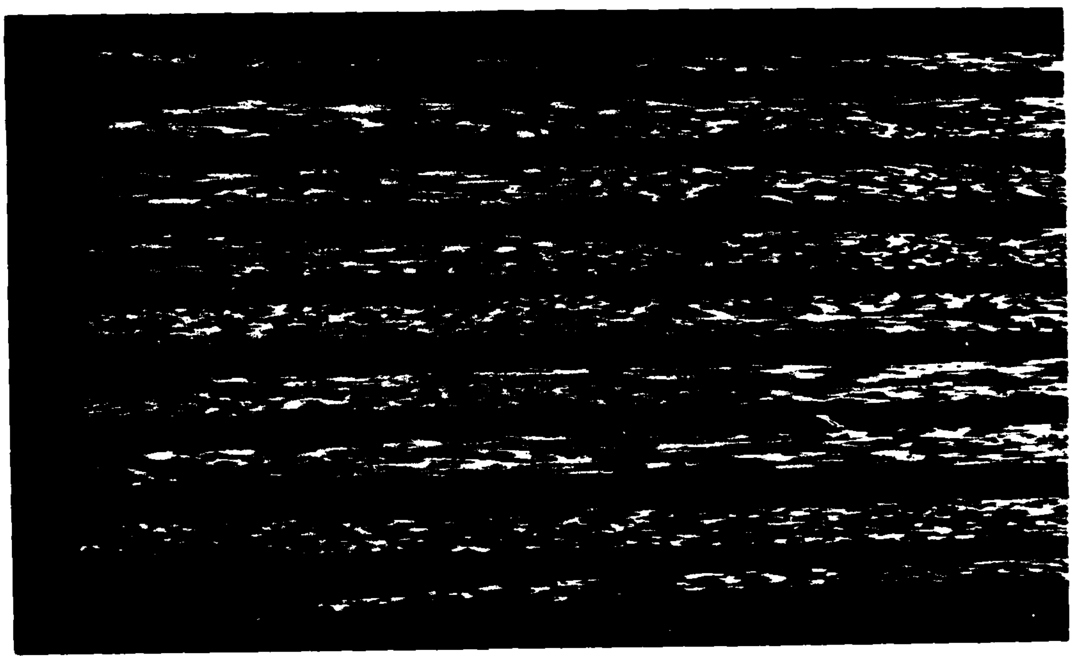


B-SCAN AT CENTER

LOCATION: 1.55 IN. DAMAGE LENGTH: 1.317



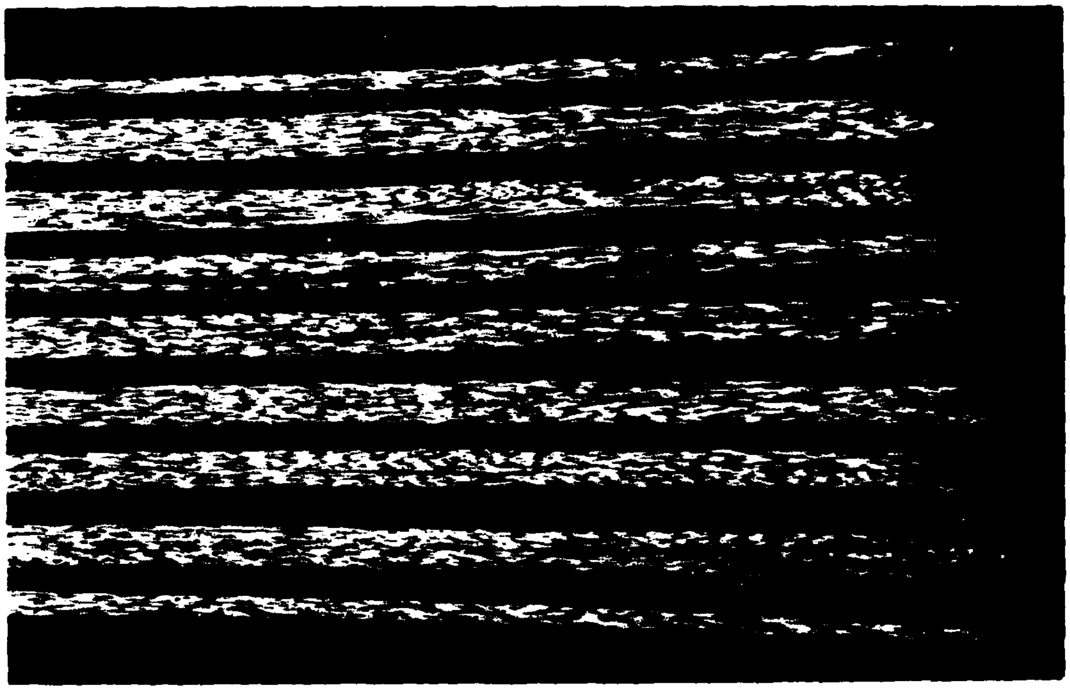
E30-12-2B 10X



E30-12-2B 25X

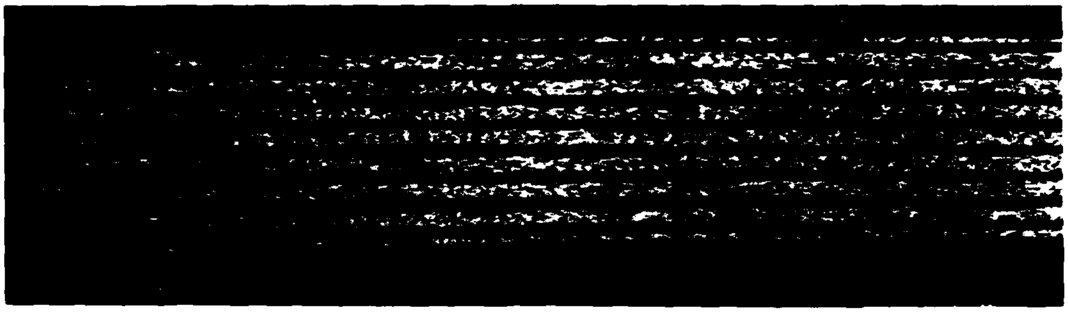
LOCATION: 1.55 IN. DAMAGE LENGTH: 1.317

E30-13-1A 10X

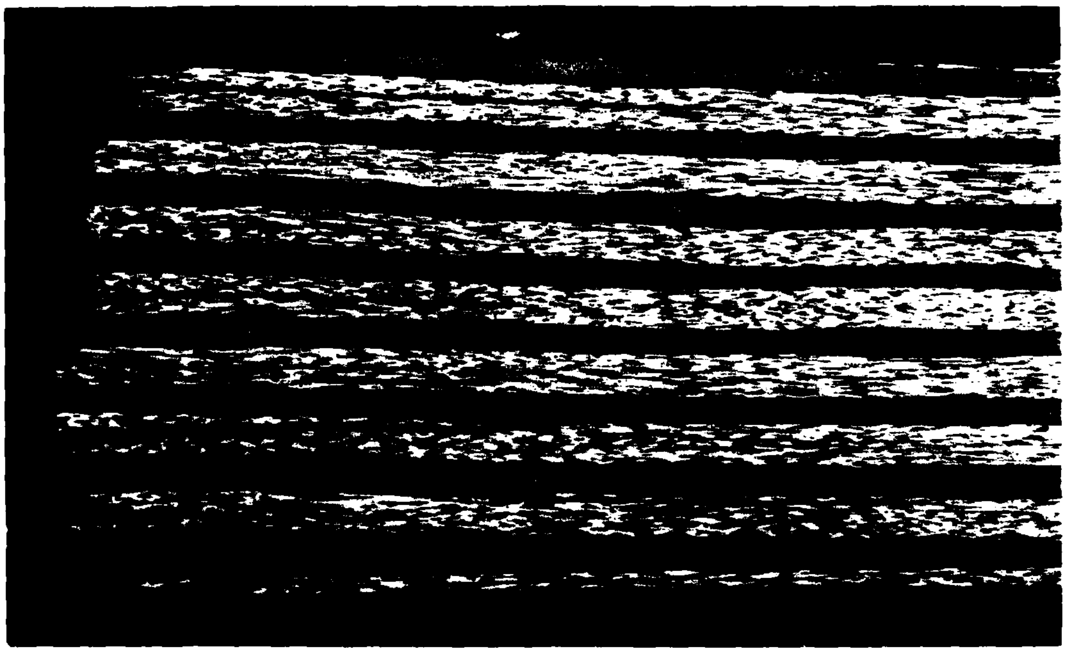


E30-13-1B 25X

LOCATION: 1.65 IN. DAMAGE LENGTH: 1.285

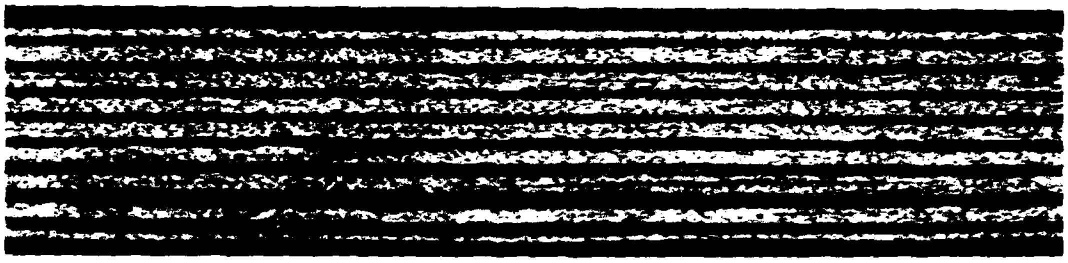


E30-13-1B 10X

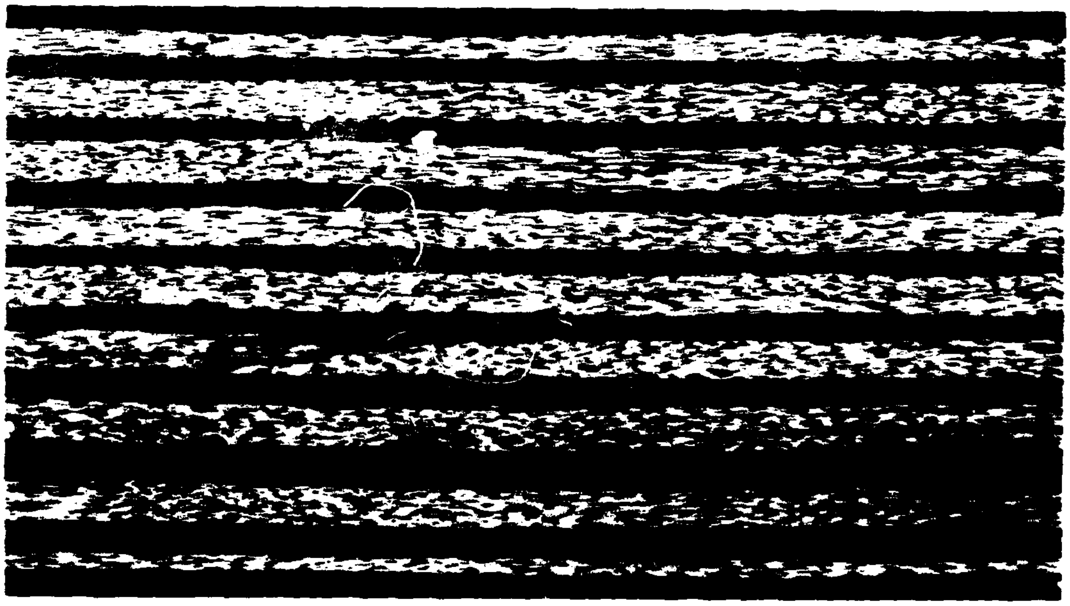


E30-13-2B 25X

LOCATION: 1.65 IN. DAMAGE LENGTH: 1.285

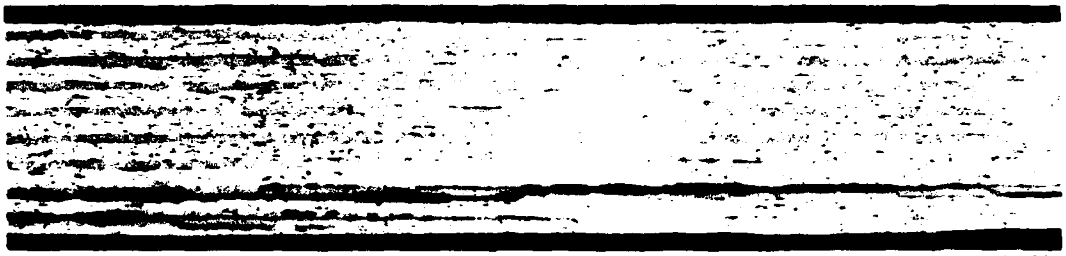


E30-14-1 10X

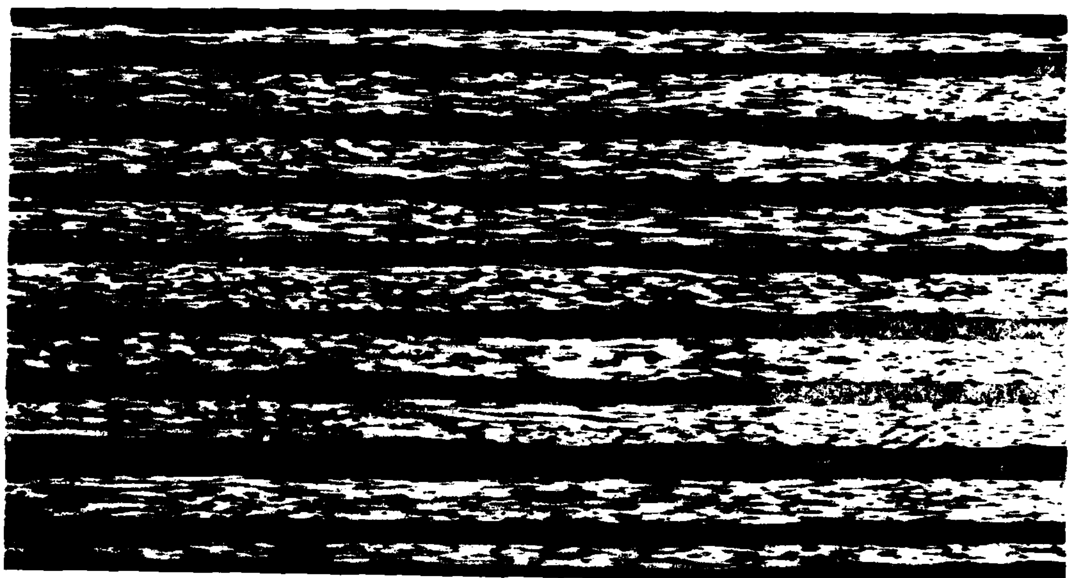


E30-14-2 25X

LOCATION: 1.75 IN. DAMAGE LENGTH: 1.260



E30-15-1 10X

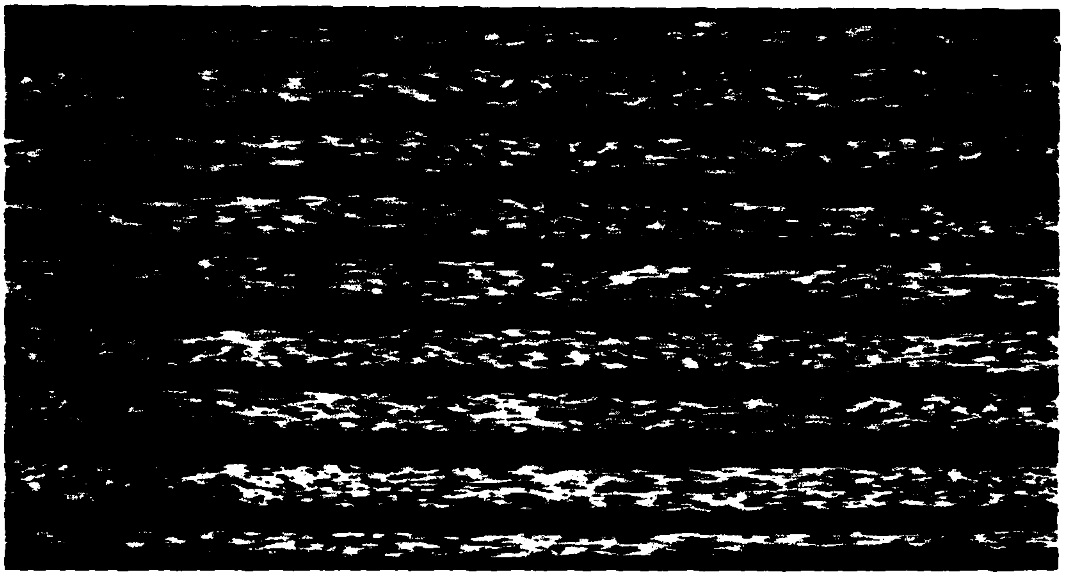


E30-15-2 25X

LOCATION: 1.85 IN. DAMAGE LENGTH: 1.297

E30-16-1

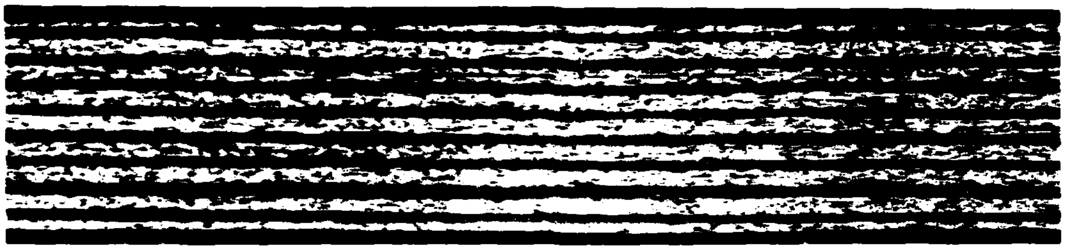
10X



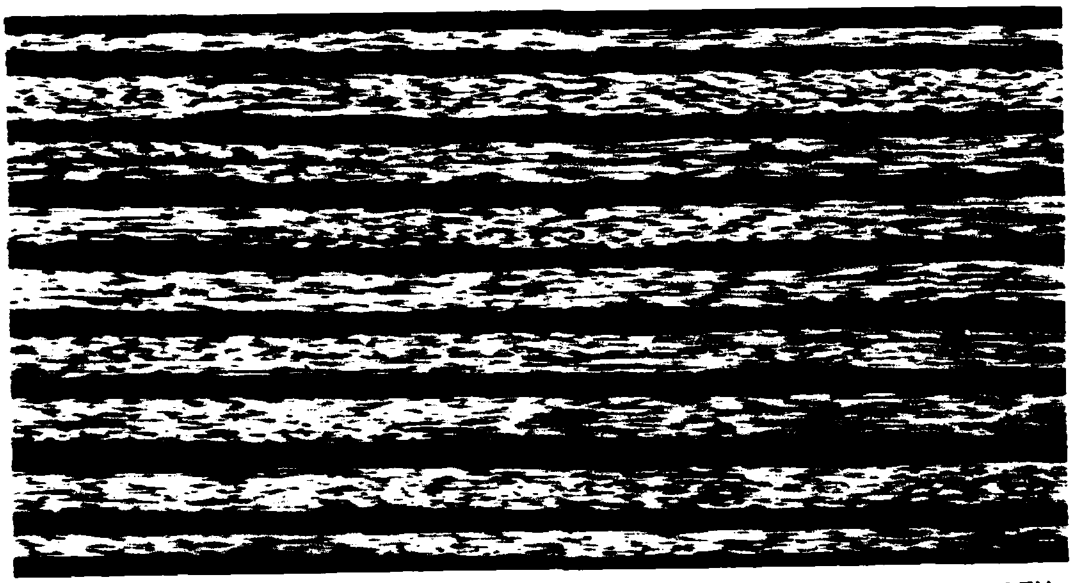
E30-16-2

25X

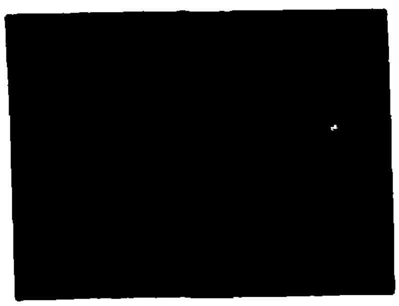
LOCATION: 1.95 IN. DAMAGE LENGTH: 1.205



E30-17-1 10X

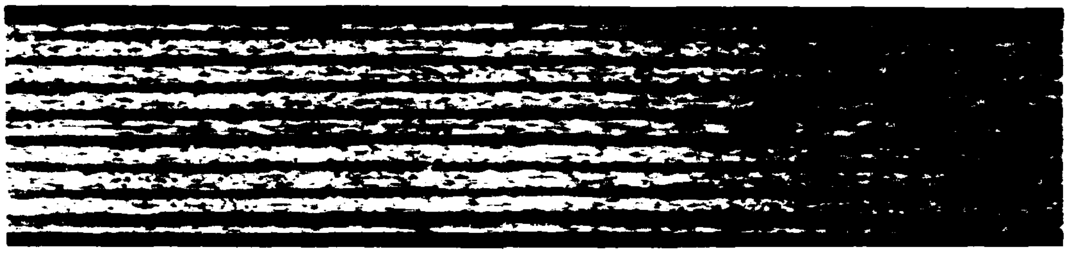


E30-17-2 25X

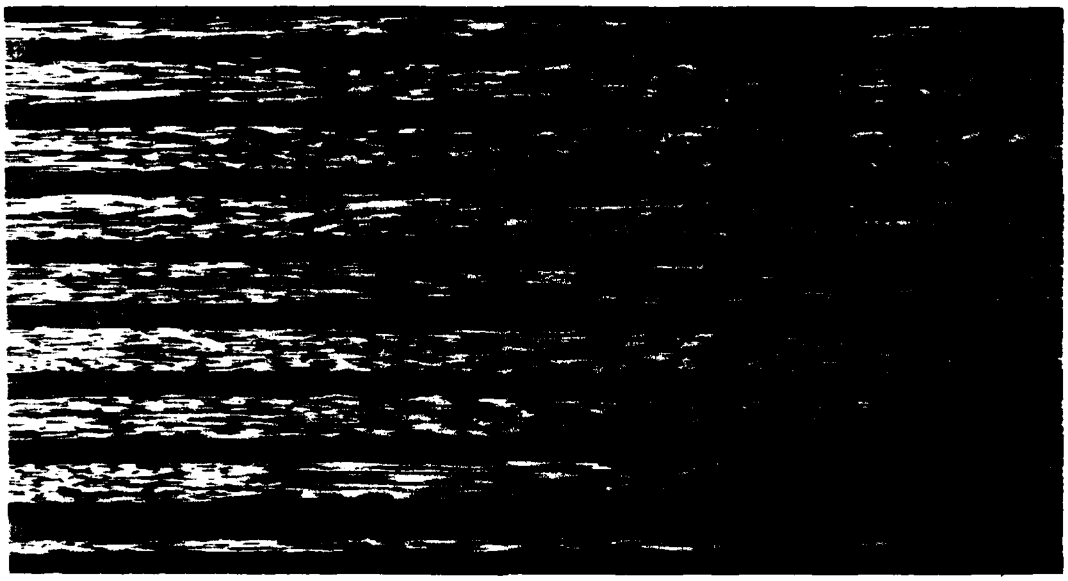


B-SCAN AT 2.08 IN.

LOCATION: 2.05 IN. DAMAGE LENGTH: 1.130



E30-18-1 10X



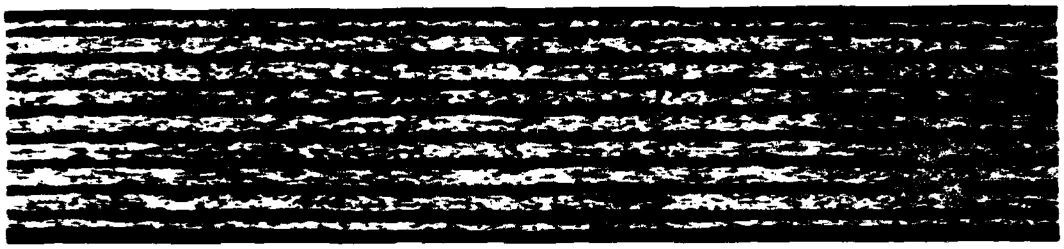
E30-18-2 25X

LOCATION: 2.15 IN. DAMAGE LENGTH: 1.112

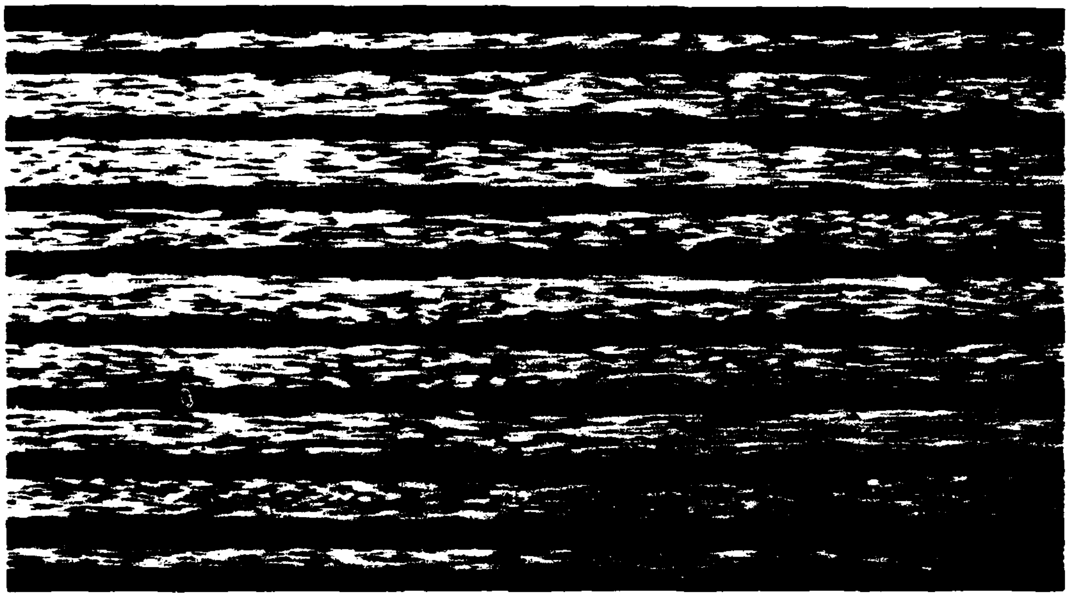
E30-19-1 10X

E30-19-2 25X

LOCATION: 2.25 IN. DAMAGE LENGTH: 0.907

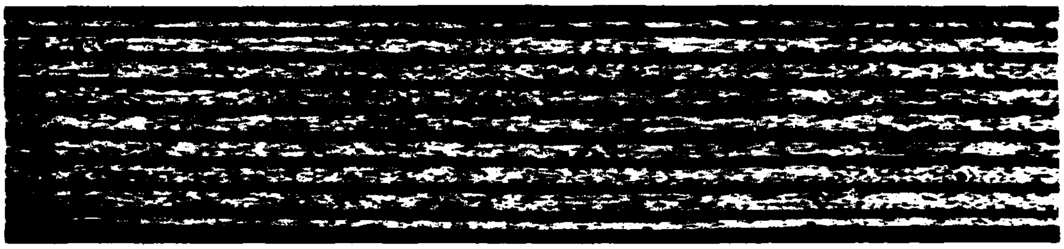


E30-20-1 10X

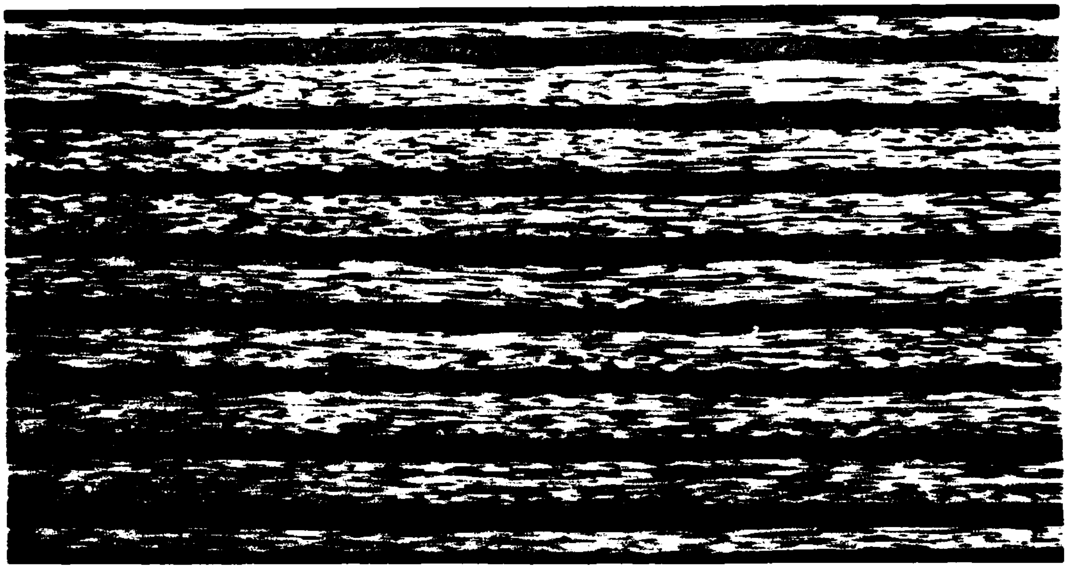


E30-20-2 25X

LOCATION: 2.35 IN. DAMAGE LENGTH: 0.571



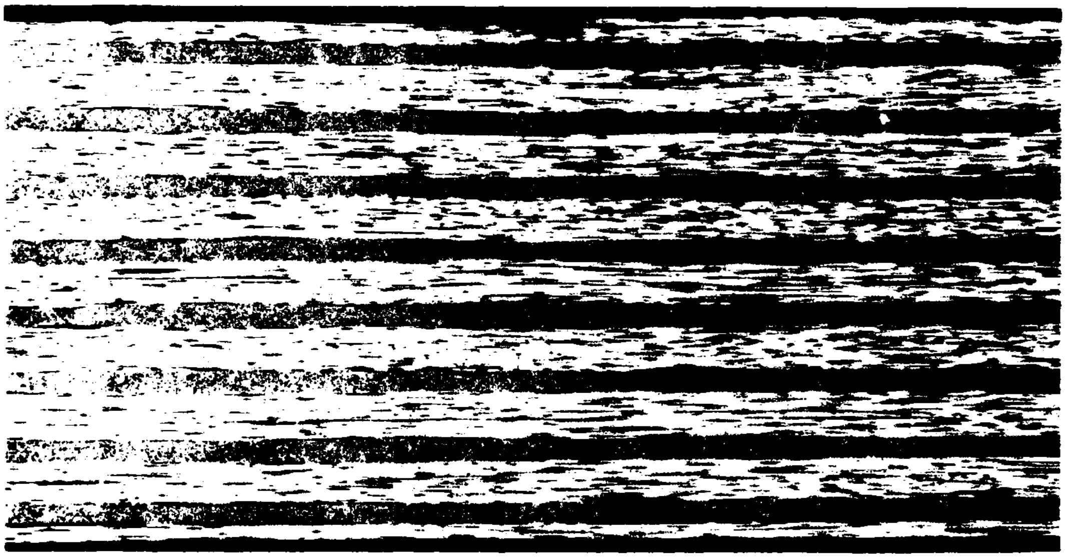
E30-21-1 10X



E30-21-2 25X

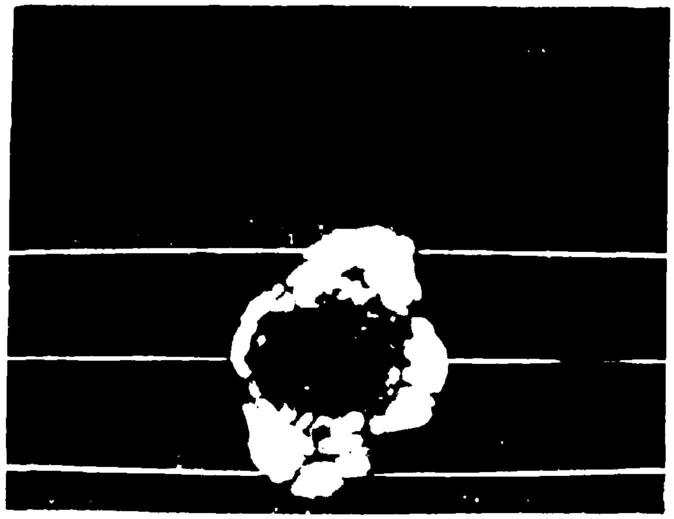
LOCATION: 2.45 IN. DAMAGE LENGTH: 0.453

E30-22-1 10X

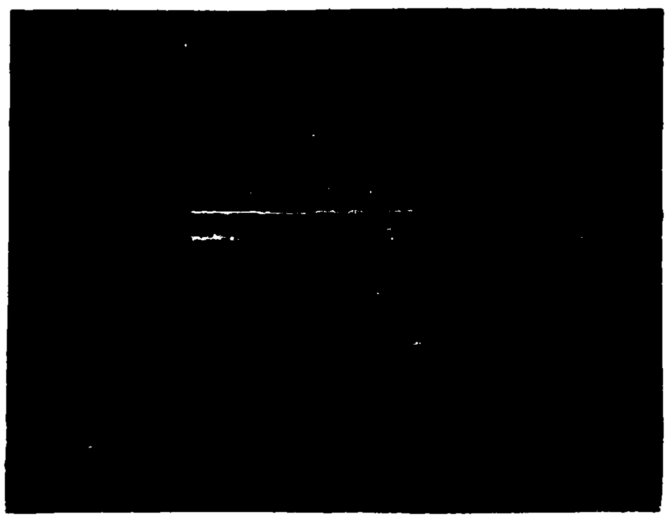


E30-22-1 25X

LOCATION: 2.55 IN. DAMAGE LENGTH: NO DAMAGE

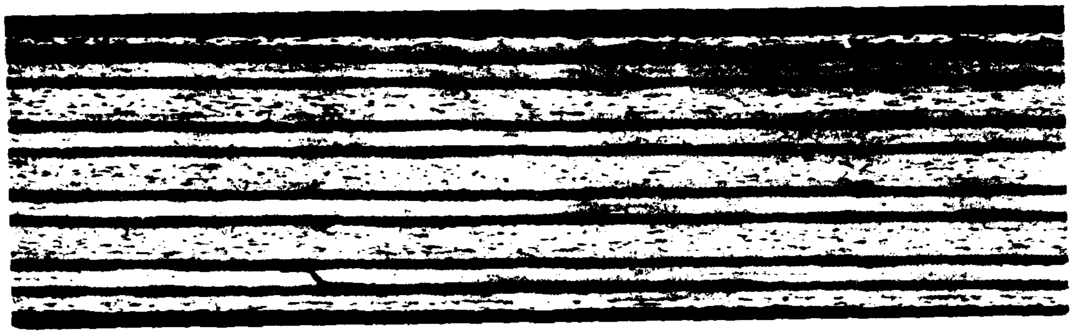


C-SCAN

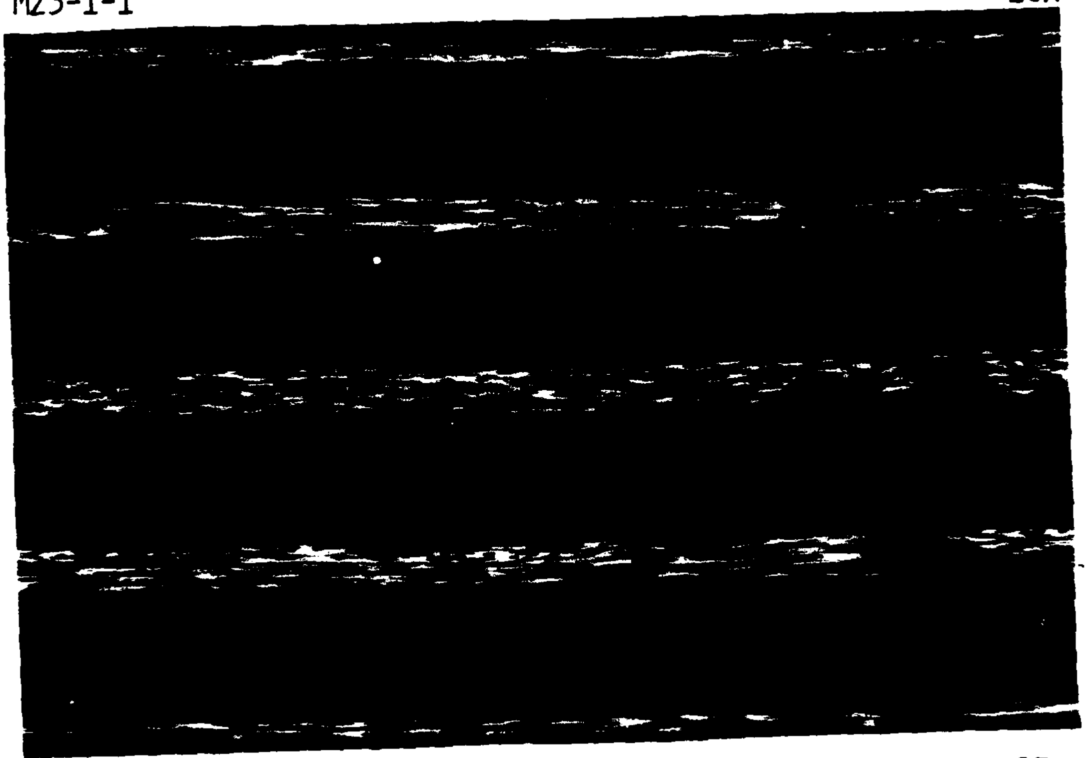


CUMULATIVE B-SCAN

32-PLY SPEC: MC-23 N_1 = 1,000 CYCLES

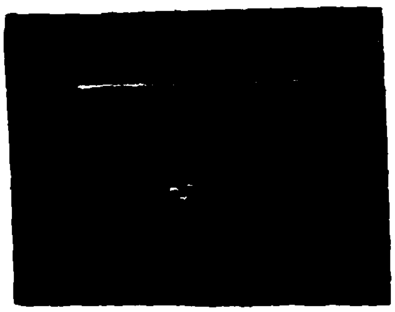


M23-1-1 10x

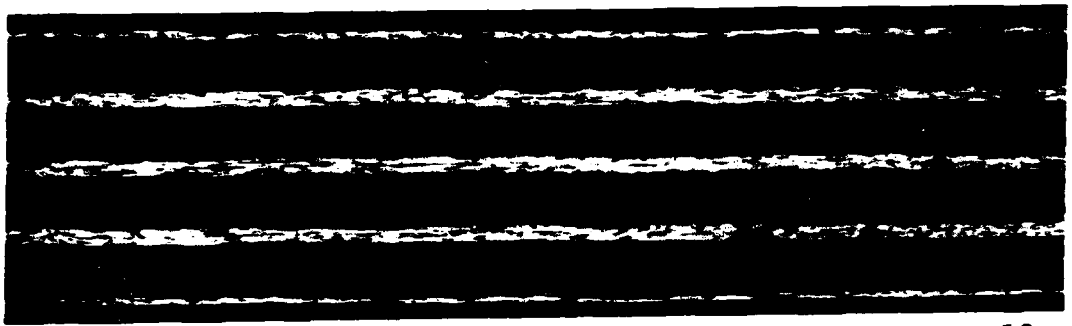


M23-1-2 25x

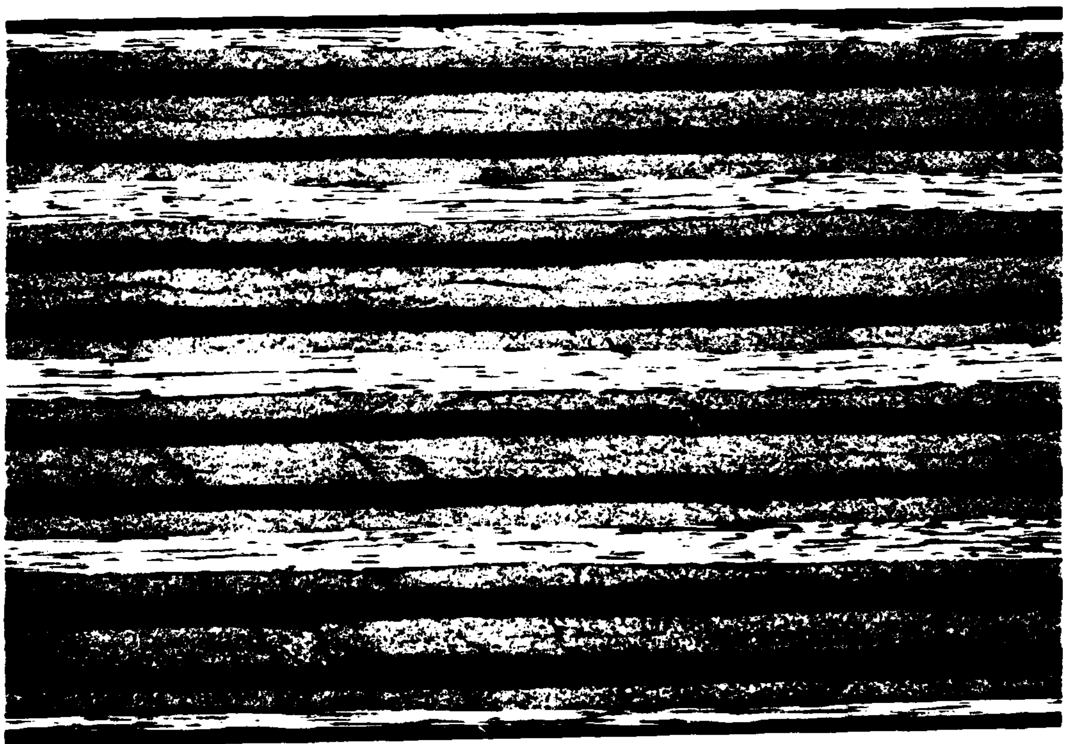
LOCATION: 1.03 IN. DAMAGE LENGTH: 0.308



B-SCAN
AT 1.03 IN.

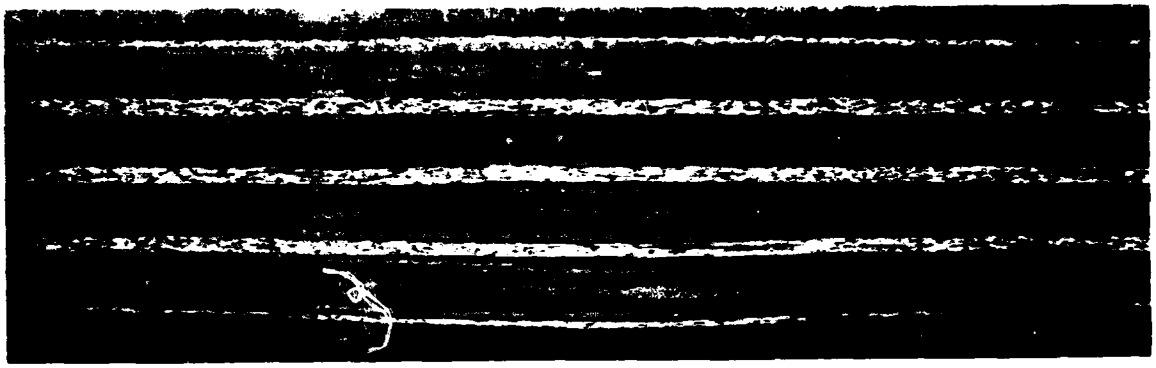


M23-2-1 10x

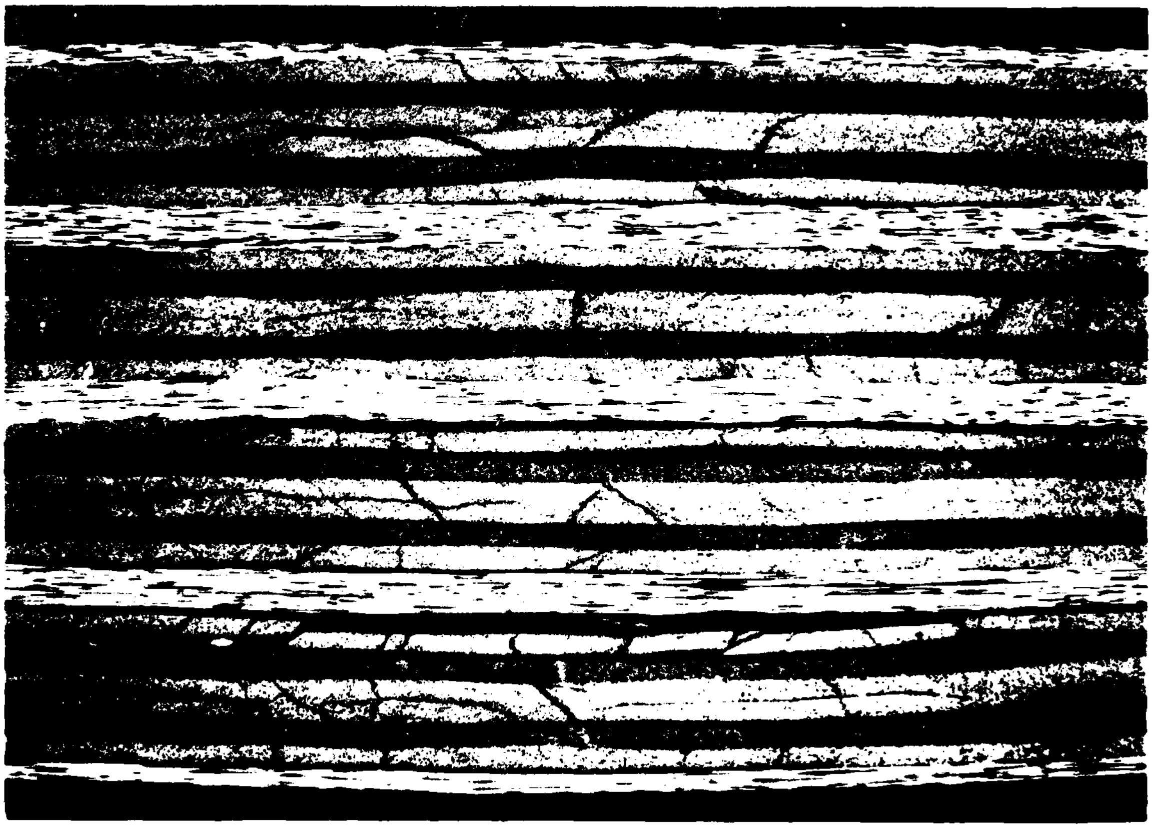


M23-2-2 25x

LOCATION: 1.13 DAMAGE LENGTH 0.479 IN.

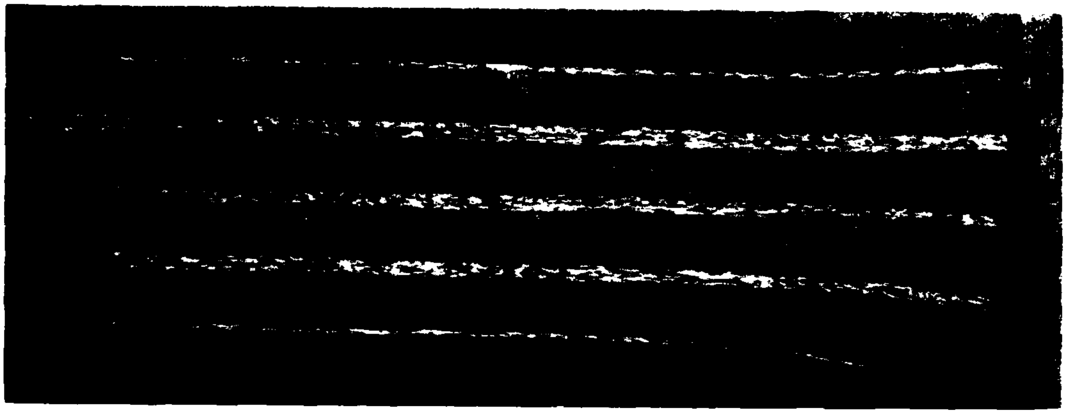


M23-3-1 10x

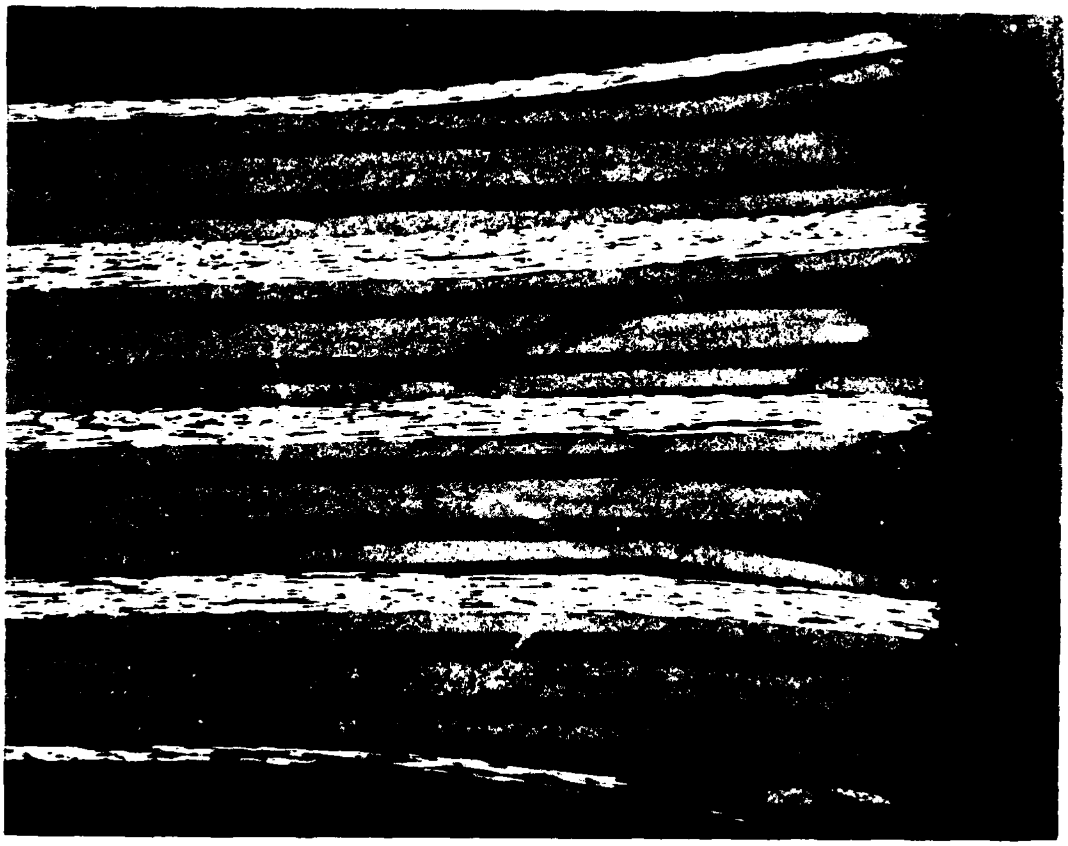


M23-3-2 25x

LOCATION: 1.23 IN. DAMAGE LENGTH: 0.619

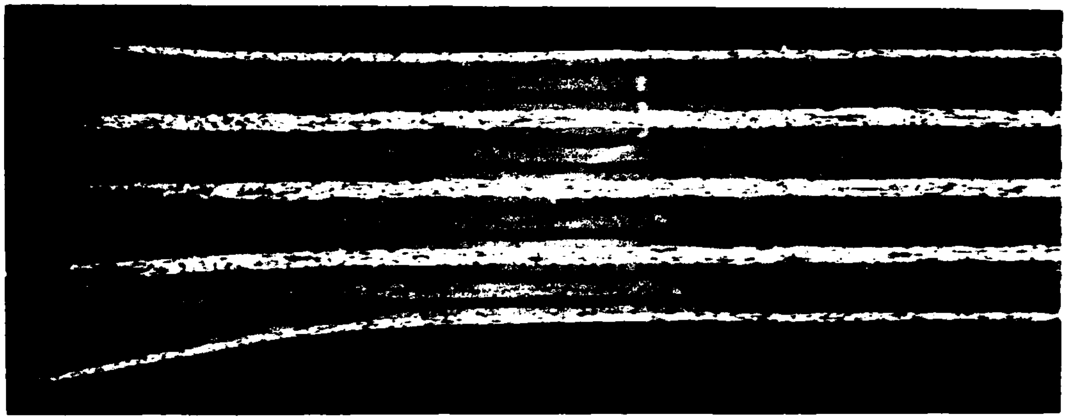


M23-4-1A 10x

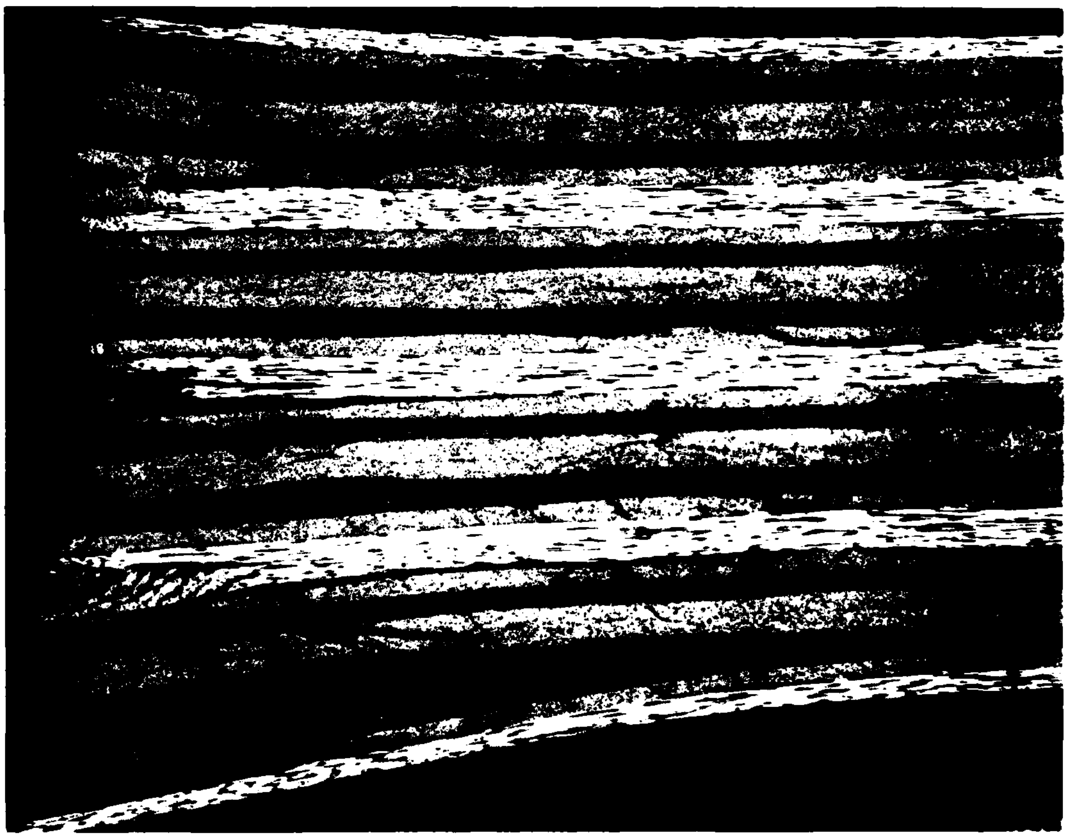


M23-4-2A 25x

LOCATION: 1.33 IN. DAMAGE LENGTH: 0.771

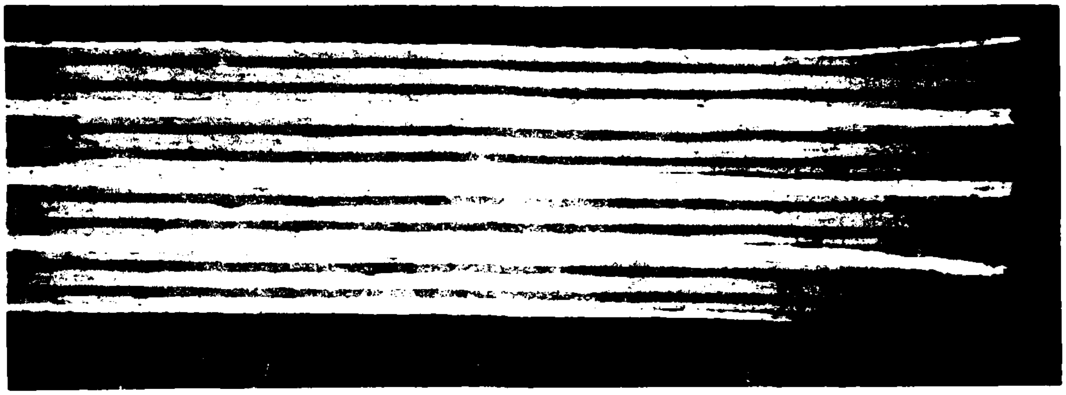


M23-4-1B 10x

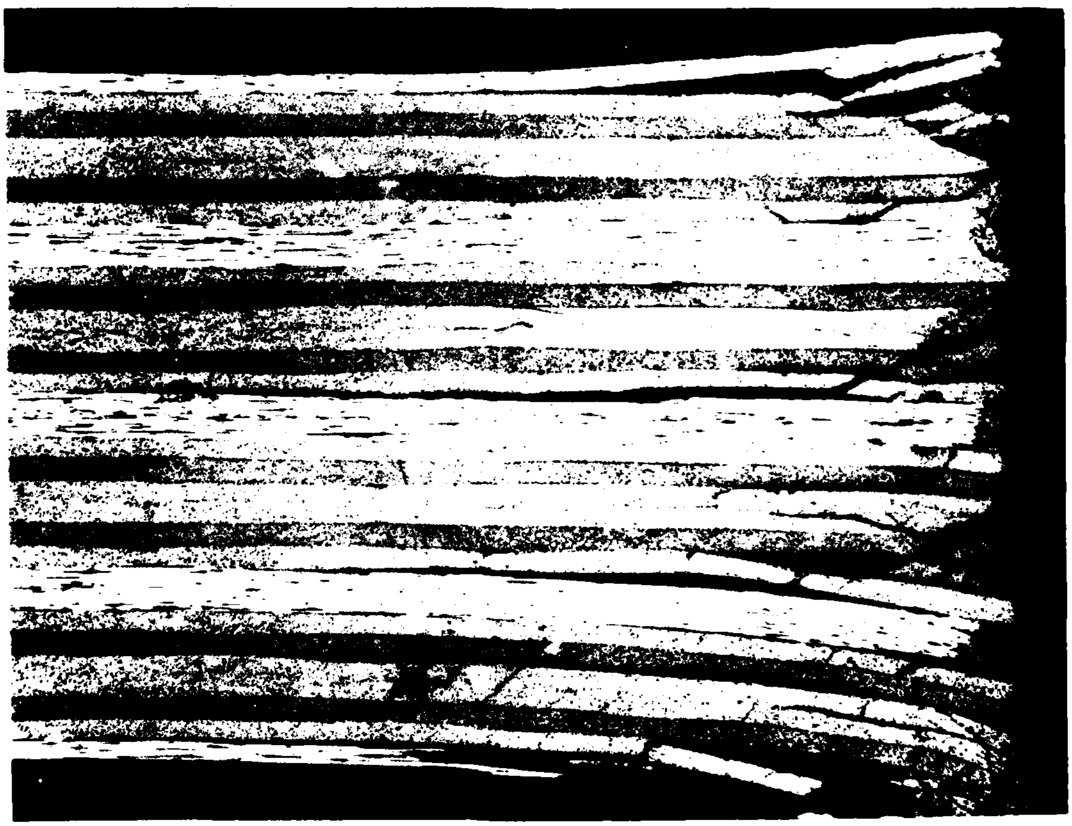


M23-4-2B 25x

LOCATION: 1.33 IN. DAMAGE LENGTH: 0.771

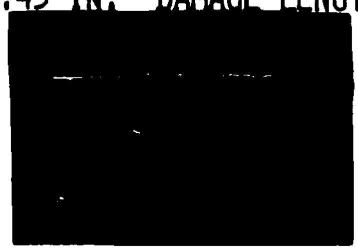


M23-5-1A 10x

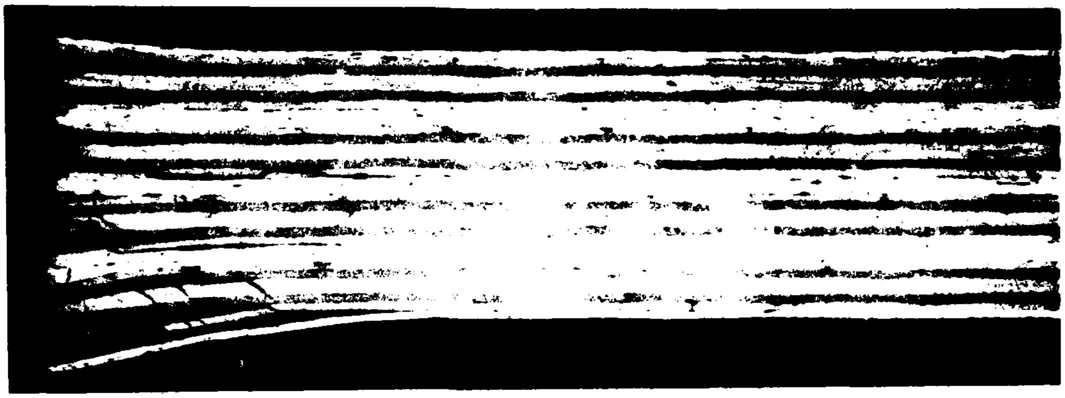


M23-5-2A 25x

LOCATION: 1.43 IN. DAMAGE LENGTH: 0.781 IN.



B-SCAN
@ 1.5 IN.

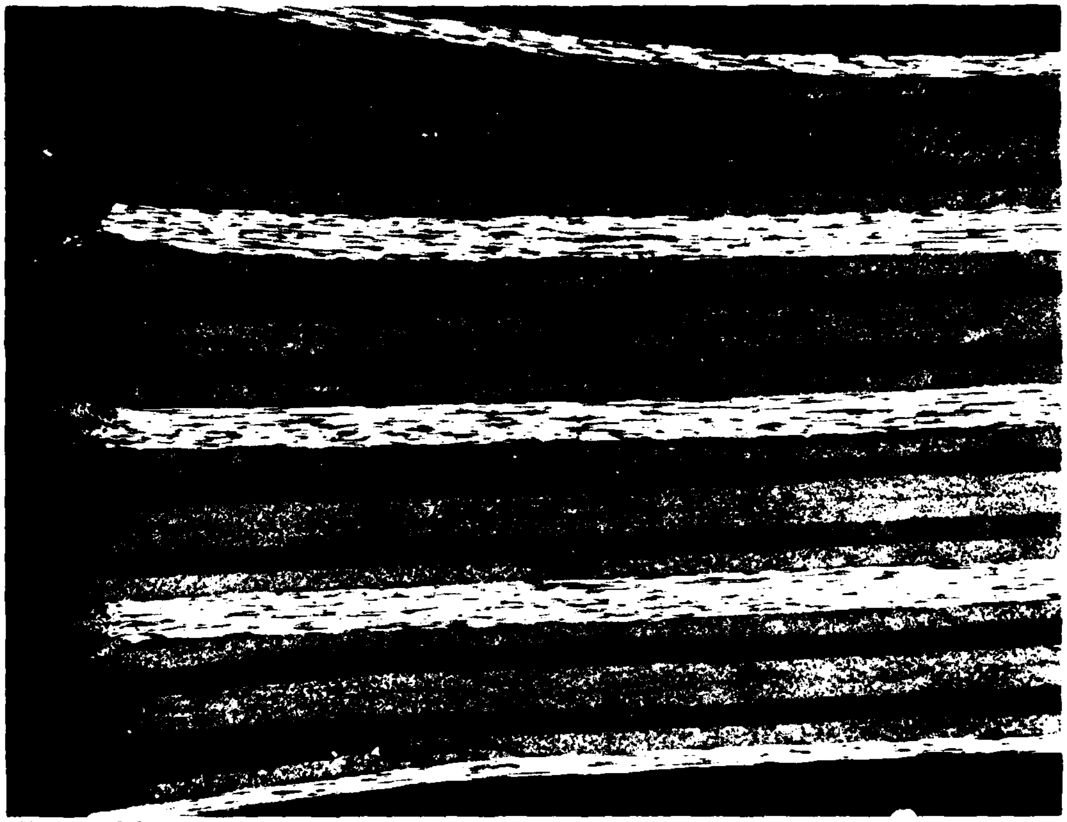


M23-5-1B 10x

M23-5-2B 25x

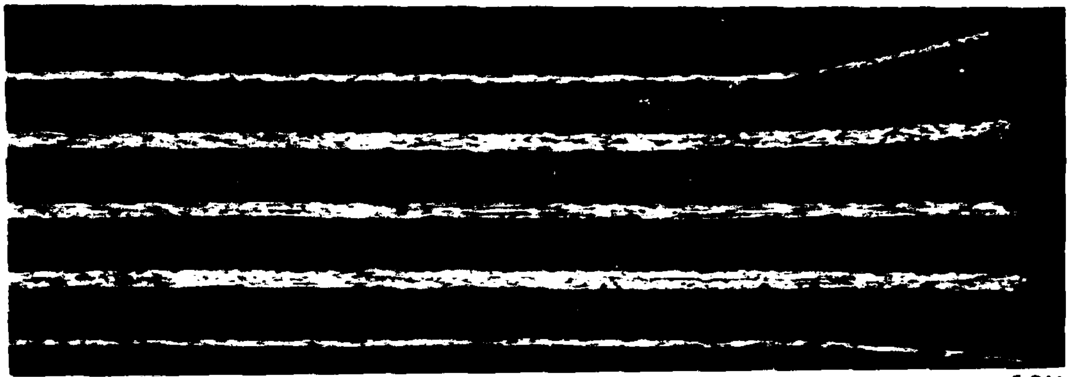
LOCATION: 1.43 IN. DAMAGE LENGTH: 0.781

M23-6-1A 10X

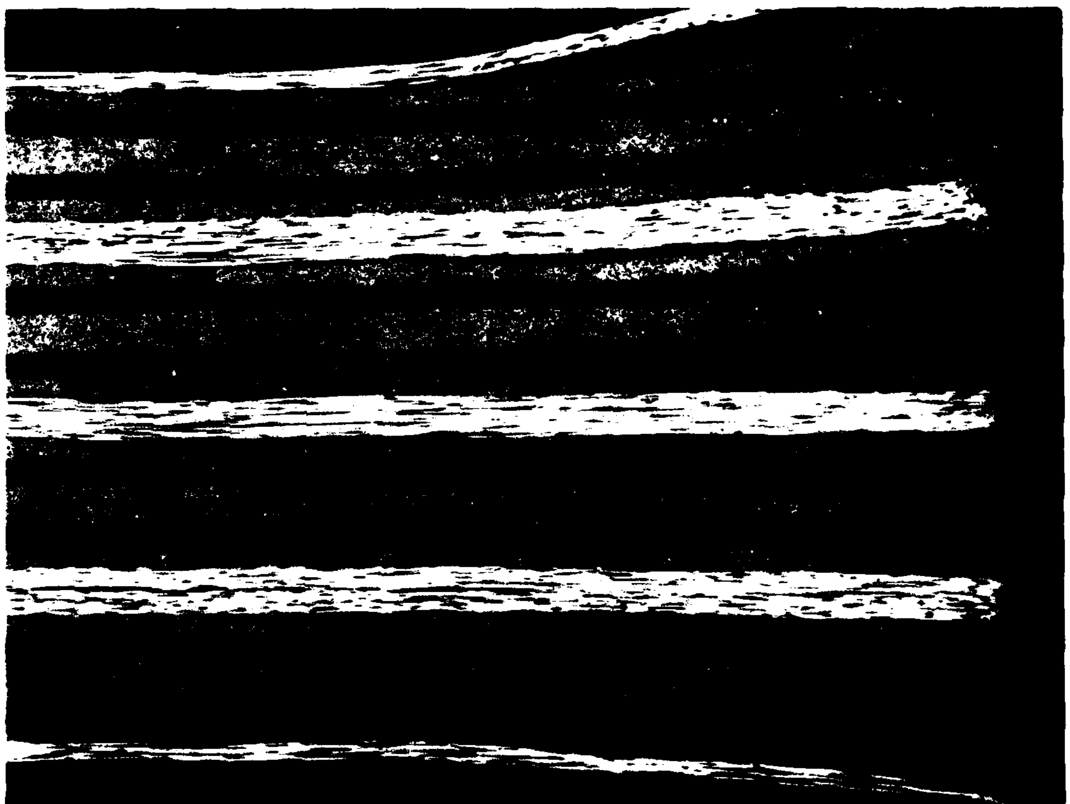


M23-6-2A 25X

LOCATION: 1.53 IN. DAMAGE LENGTH: 0.806"



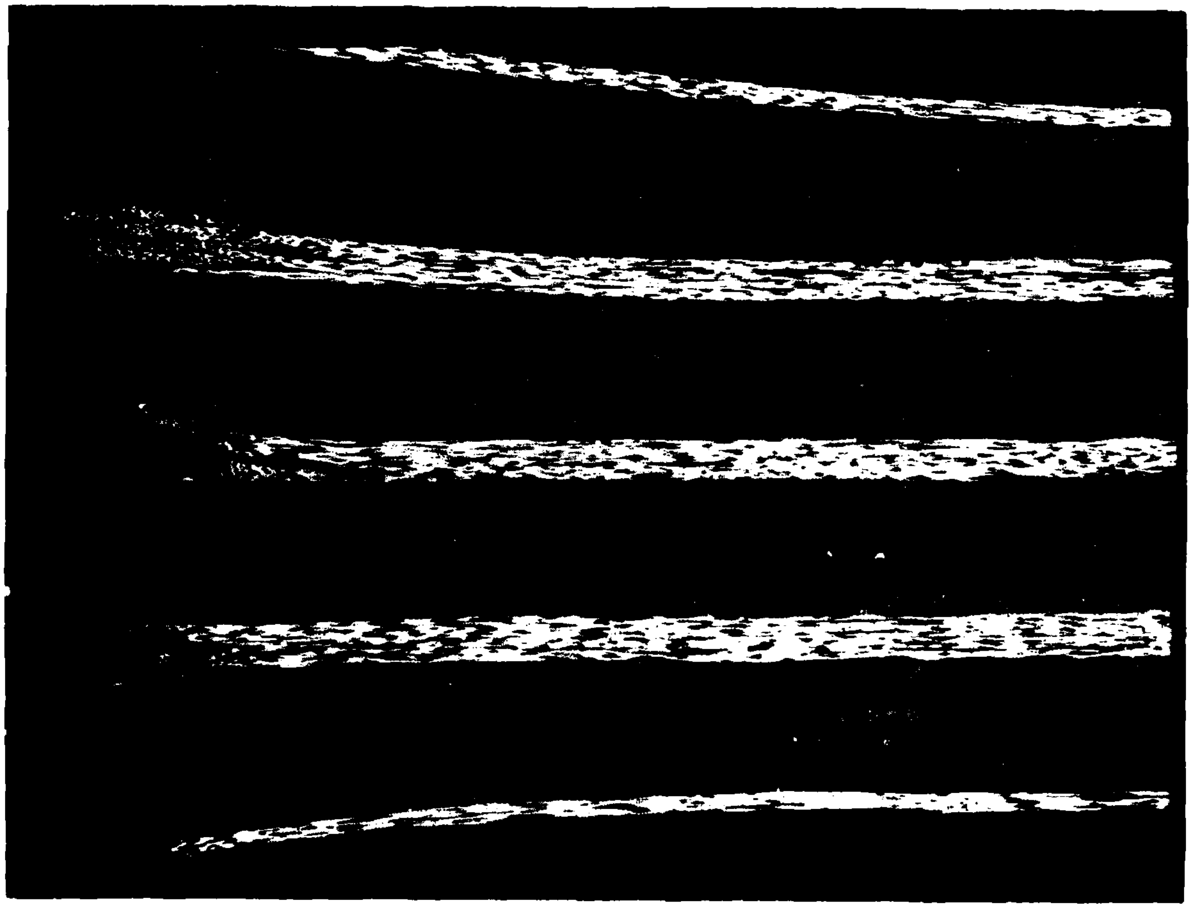
M-23-6-1B 10X



M23-6-2B 25X

LOCATION: 1.53 IN. DAMAGE LENGTH: 0.806

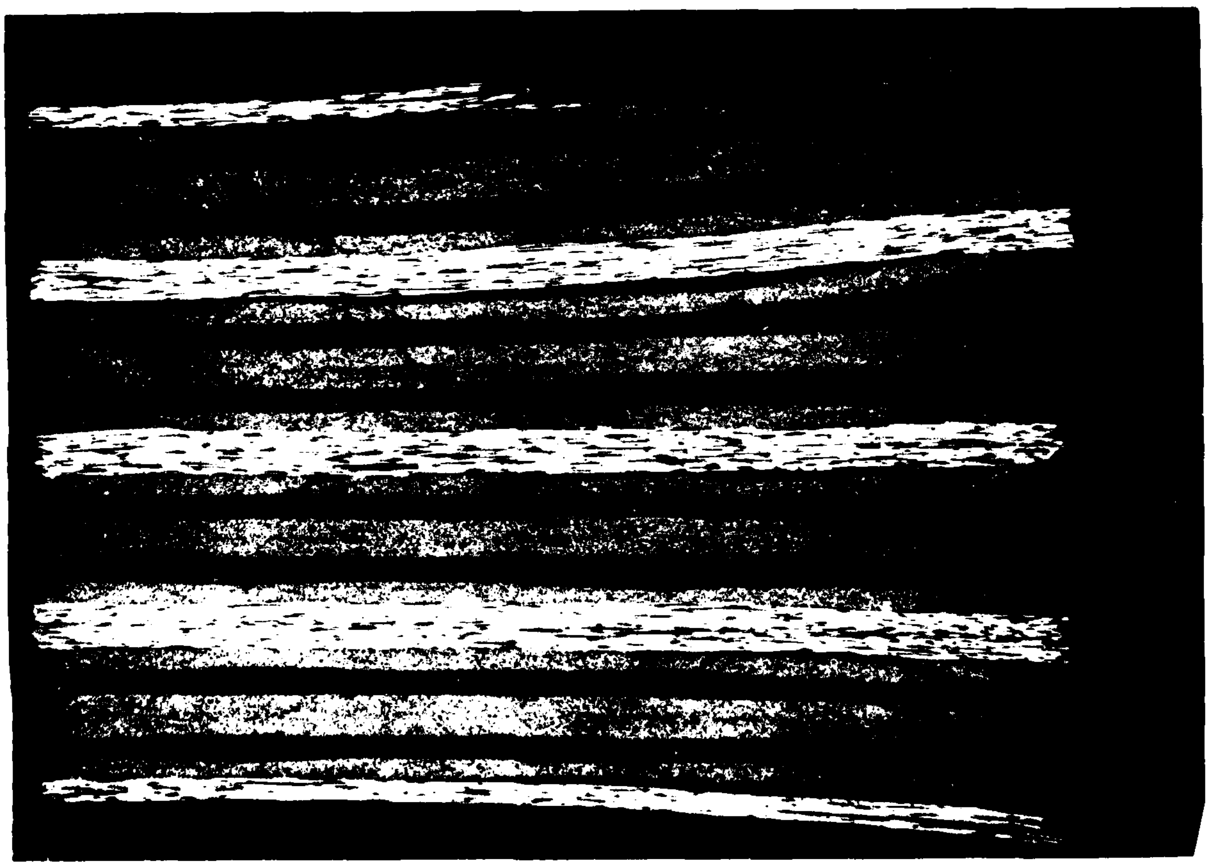
M23-7-1A 10X



M23-7-2A 25X

LOCATION: 1.63 IN. DAMAGE LENGTH: 0.750

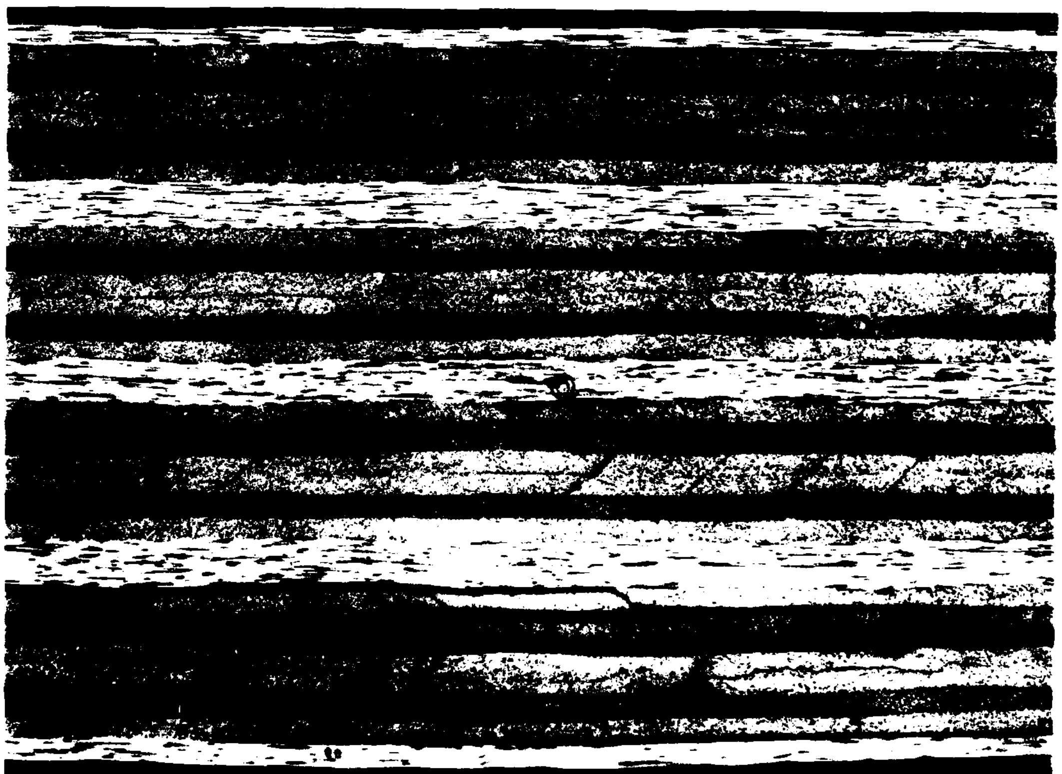
M23-7-1P 10X



M23-7-2I 25X

LOCATION: 1.63 IN. DAMAGE LENGTH: 0.750

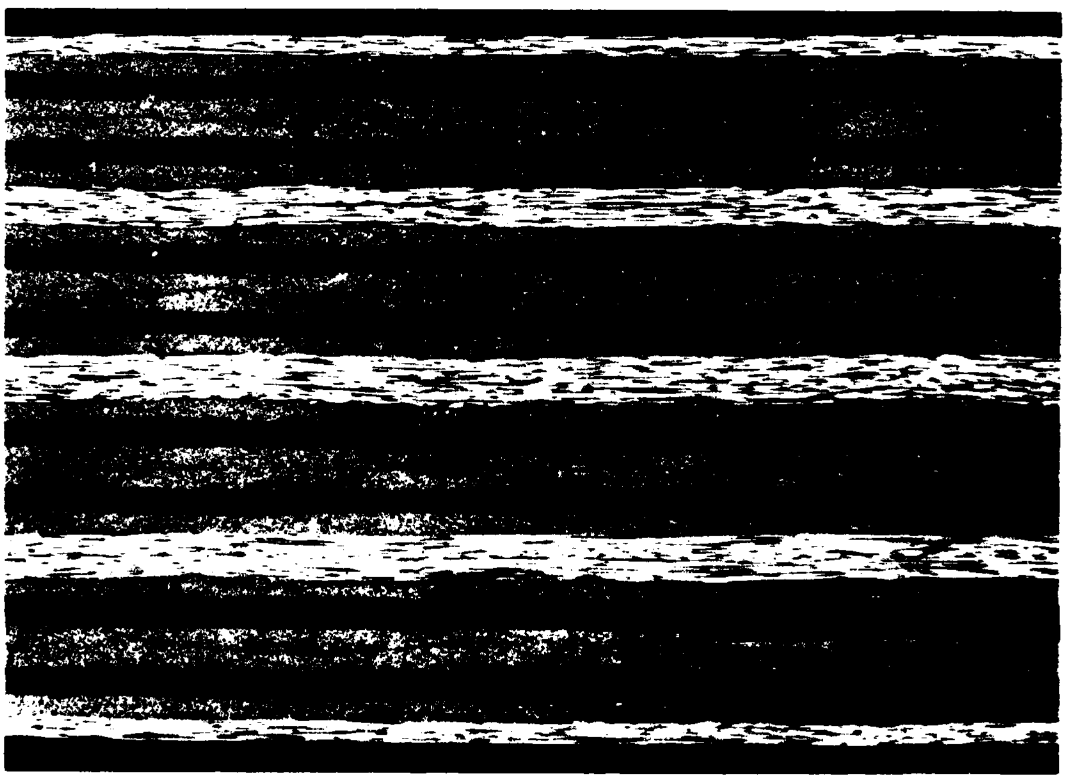
M23-8-1 10X



M23-8-2 25 X

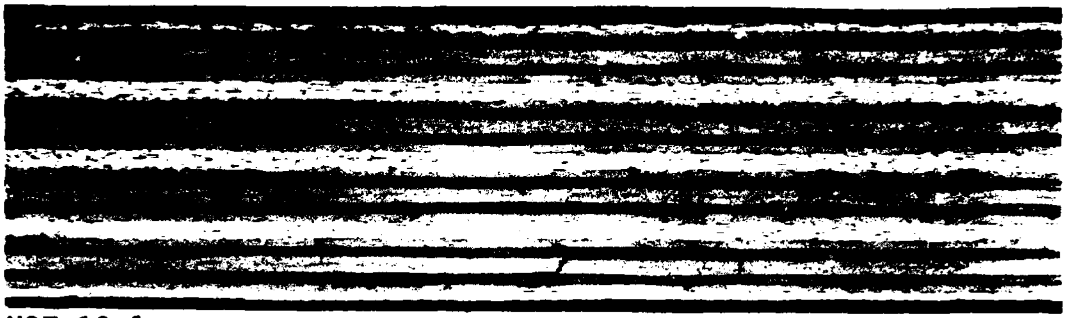
LOCATION: 1.73 IN. DAMAGE LENGTH: 0.679

M23-9-1 10X

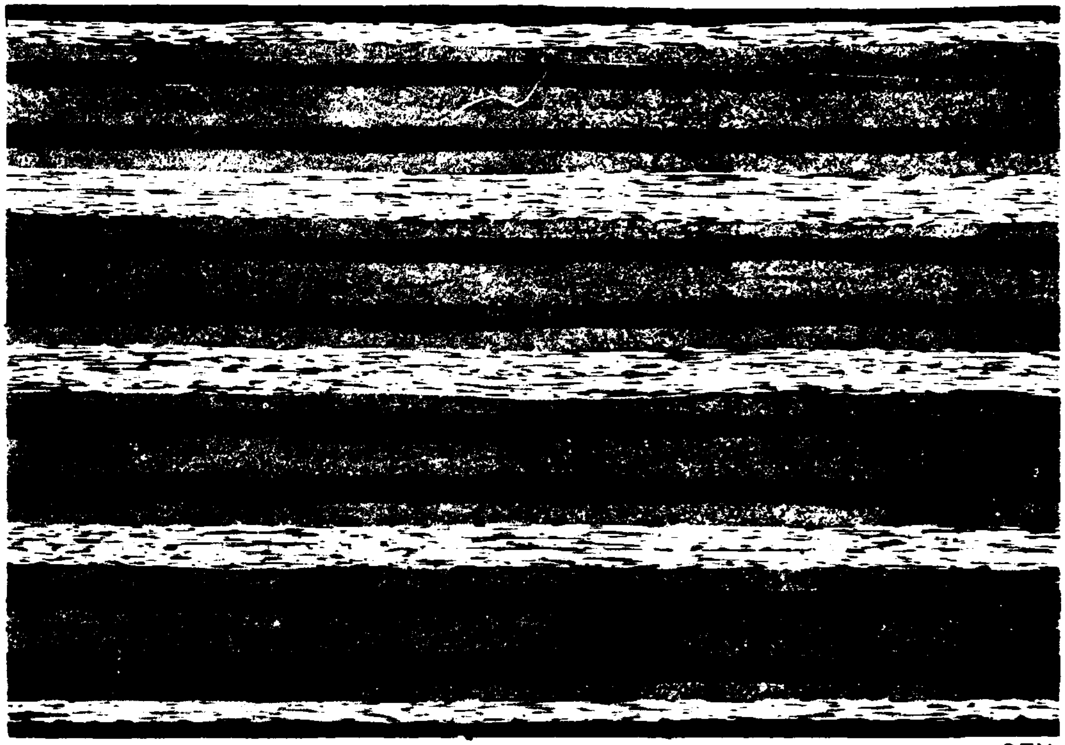


M23-9-2 25X

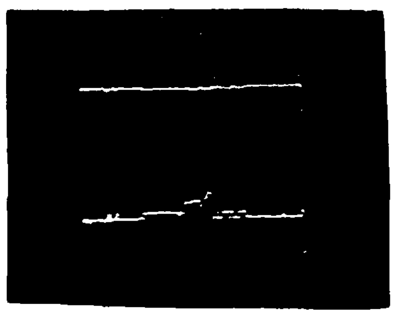
LOCATION: 1.83 IN. DAMAGE LENGTH: 0.586



M23-10-1 10X

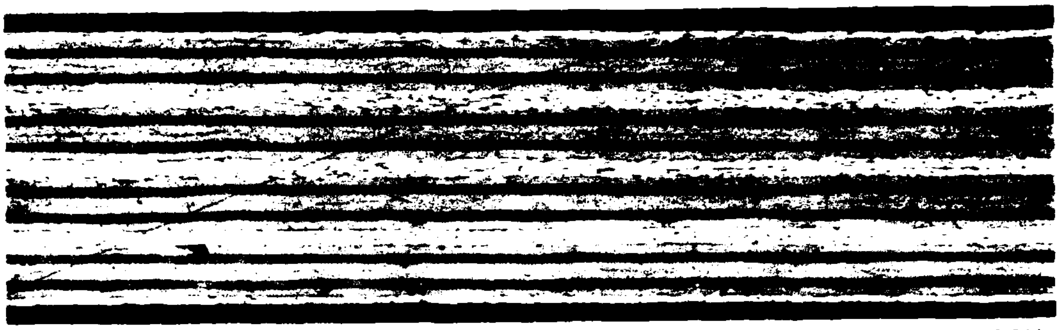


MC23-10-2 25X

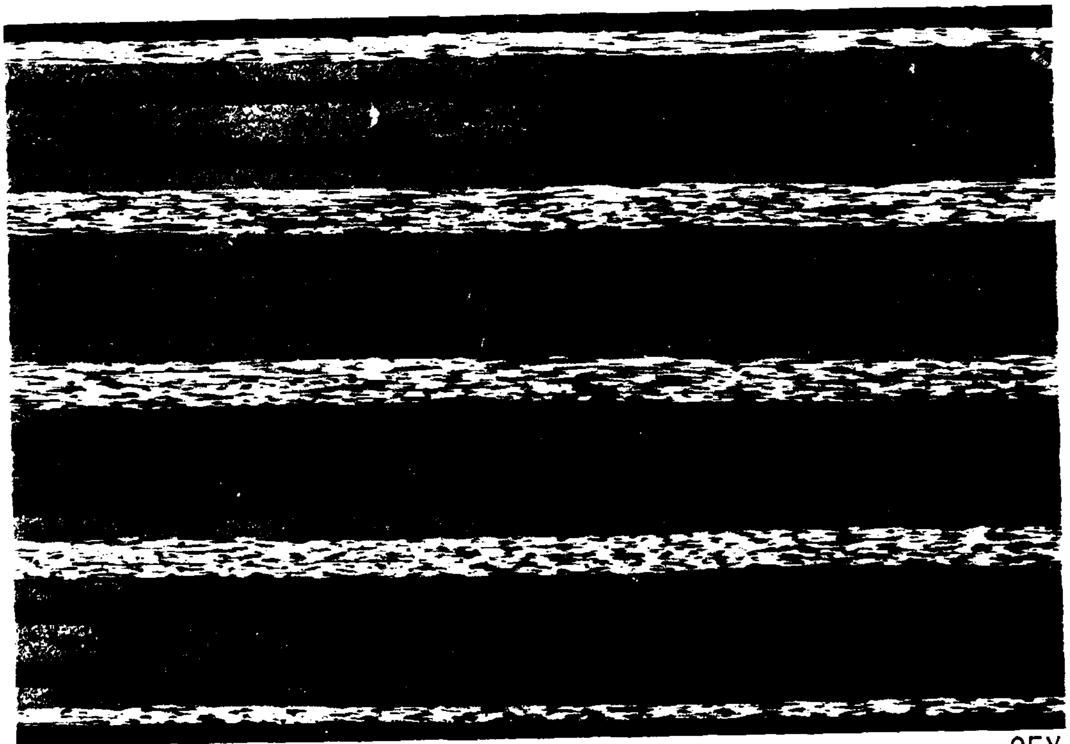


B SCAN AT 1.9

[illegible] IN. DAMAGE LENGTH: 0.434

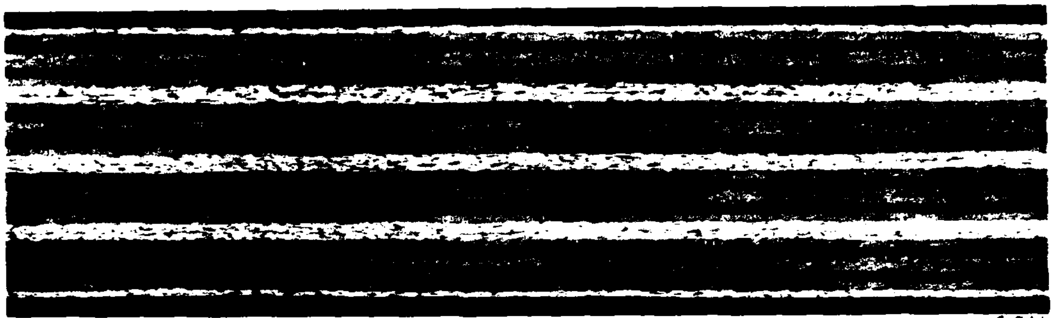


M23-11-1 10X

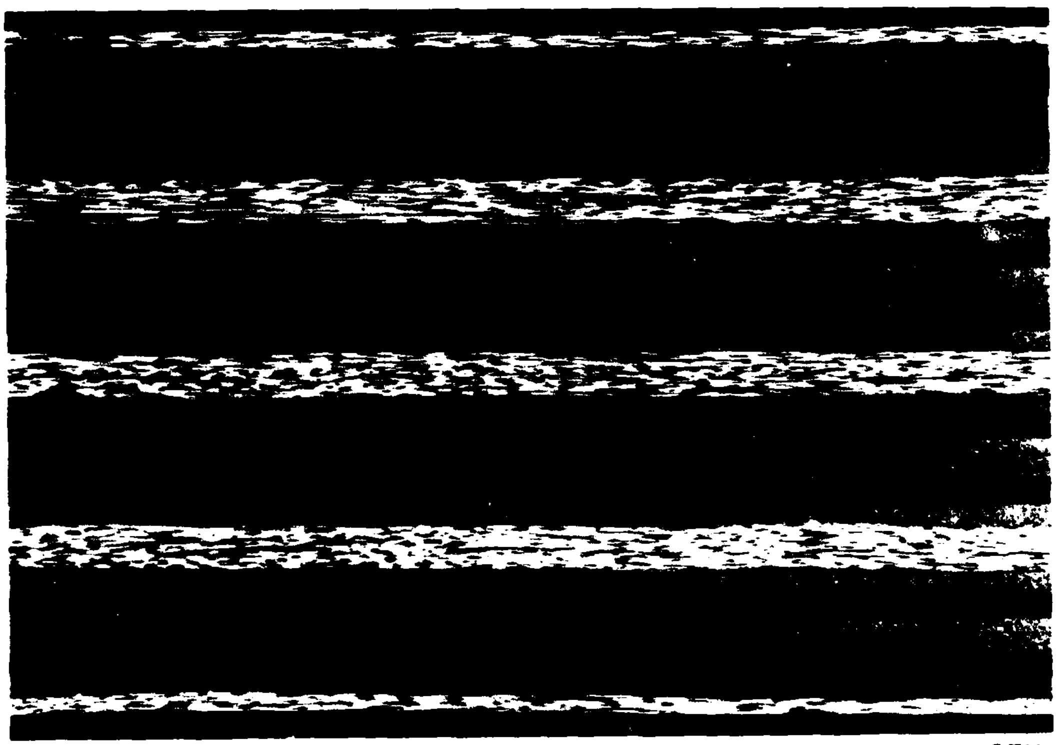


M23-11-2 25X

LOCATION: 2.03 IN. DAMAGE LENGTH: 0.188

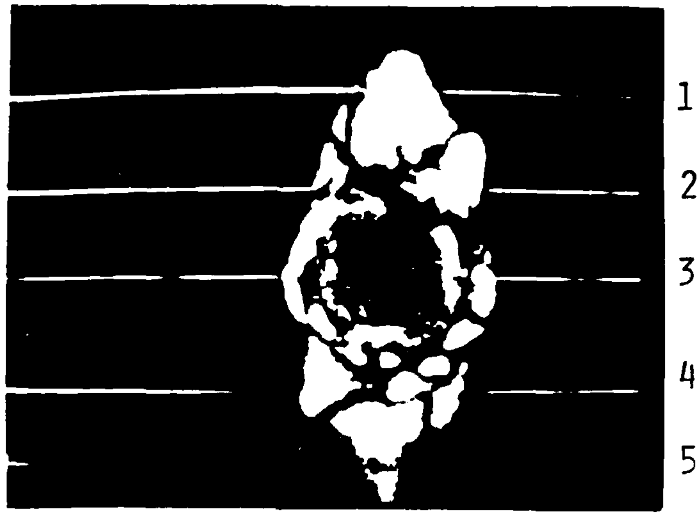


M23-12-1 10X

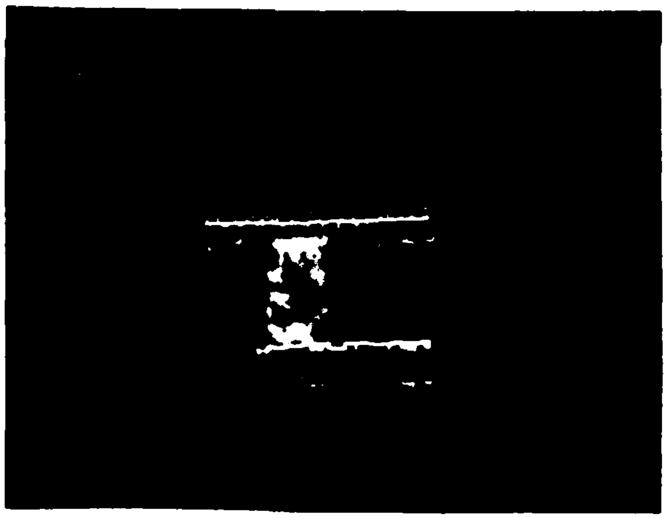


M23-12-2 25X

LOCATION: 2.13 IN. DAMAGE LENGTH: NO DAMAGE



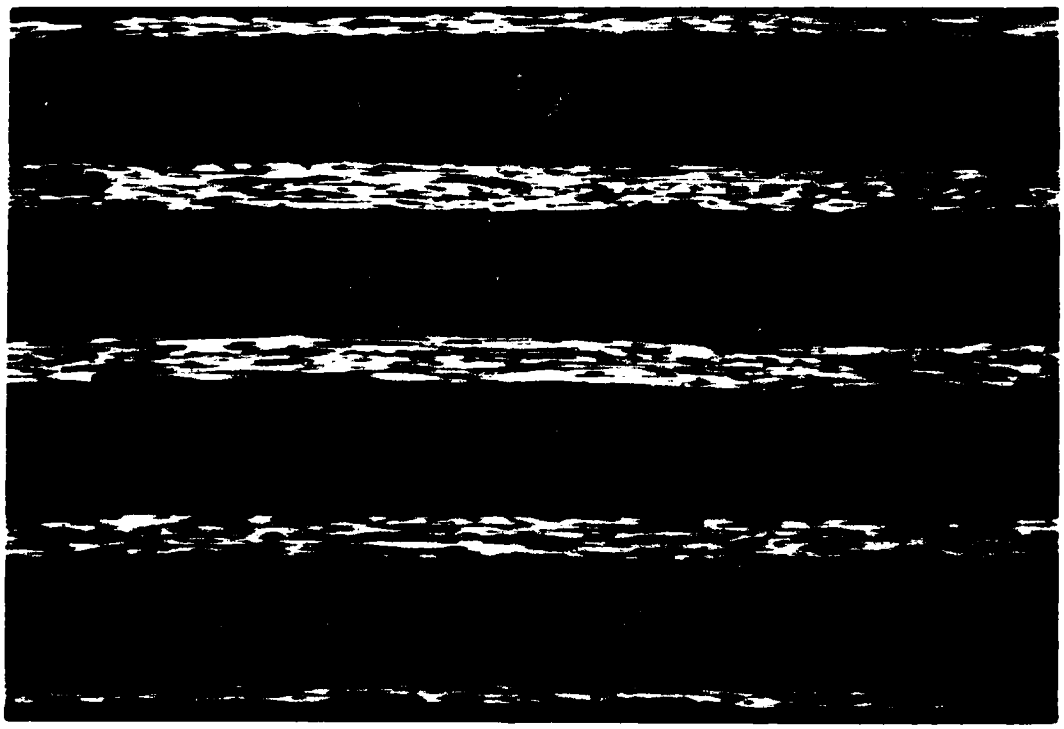
C-SCAN



CUMULATIVE B-SCAN

32-PLY SPEC: MC-22 N_2 = 5,000 CYCLES

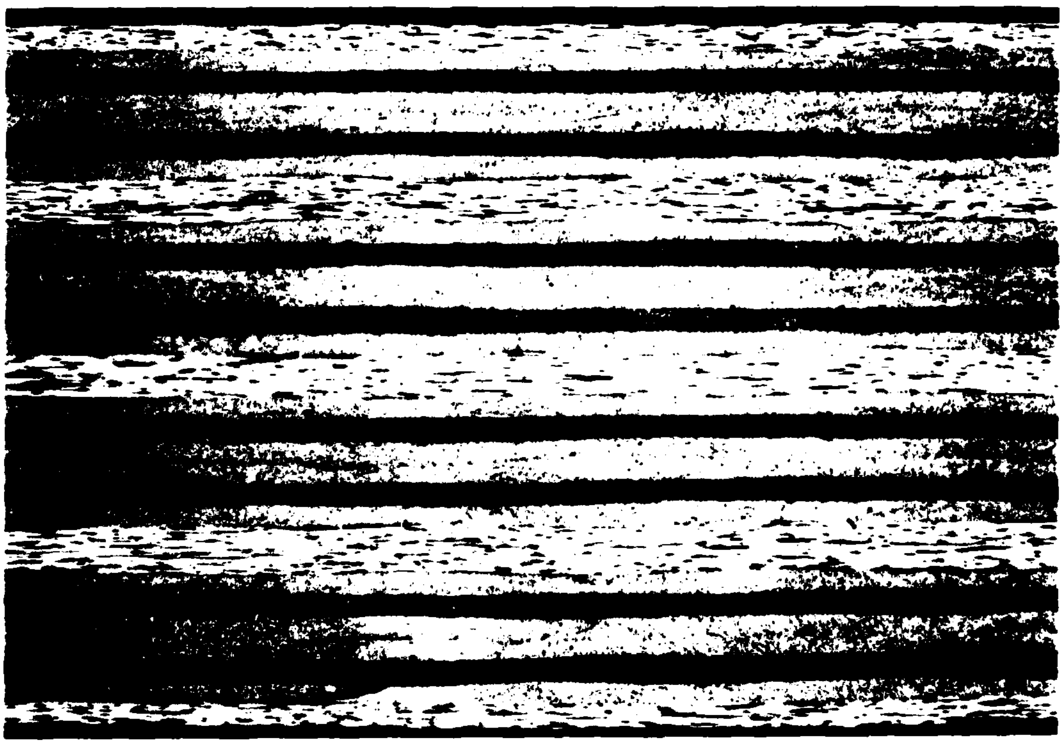
M22-1-1 10X



M22-1-2 25X

LOCATION: 0.69 IN. DAMAGE LENGTH: No CRACKS

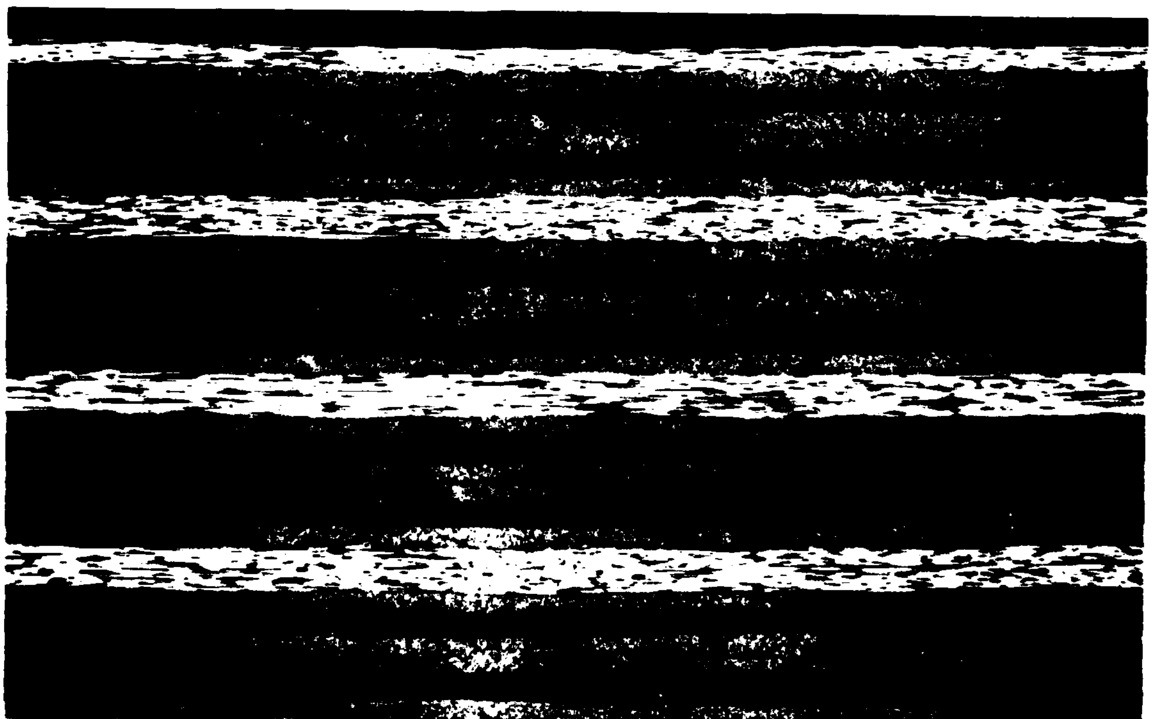
M22-2-1 10X



M22-2-2 25X

LOCATION: 0.79 IN. DAMAGE LENGTH: 0.318

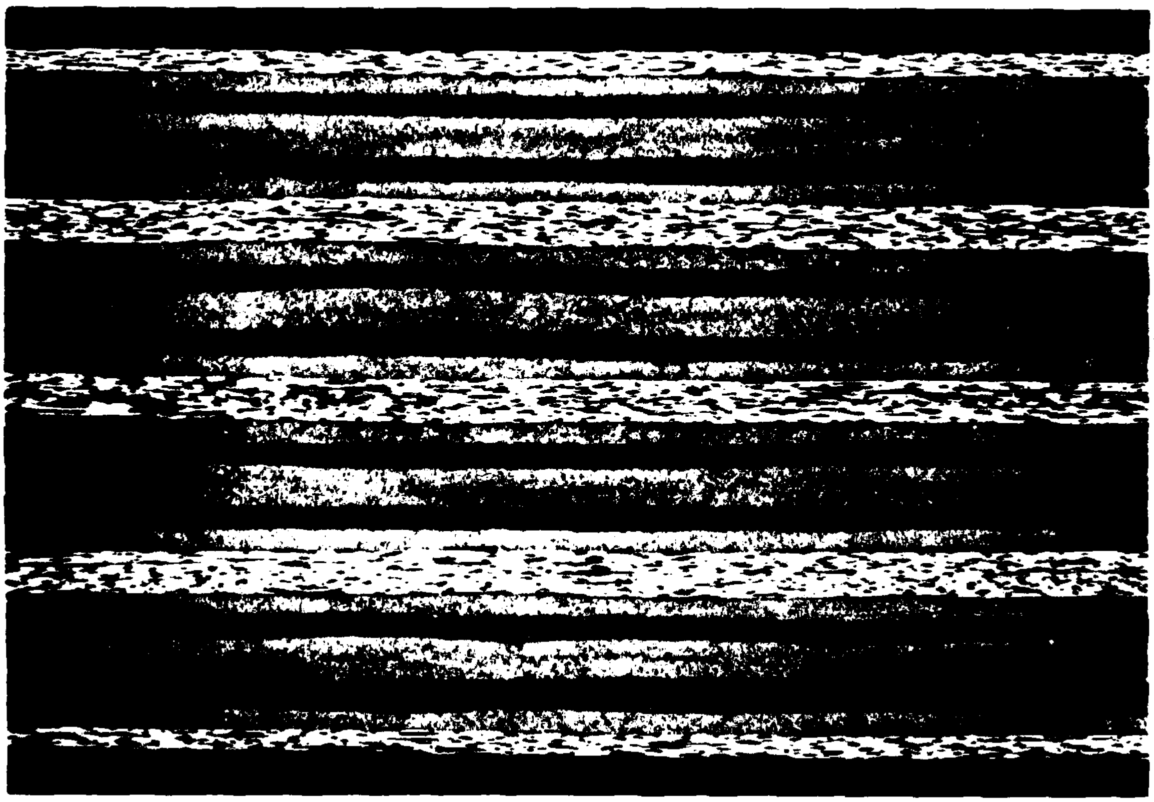
M22-3-1 10X



M22-3-2 25X

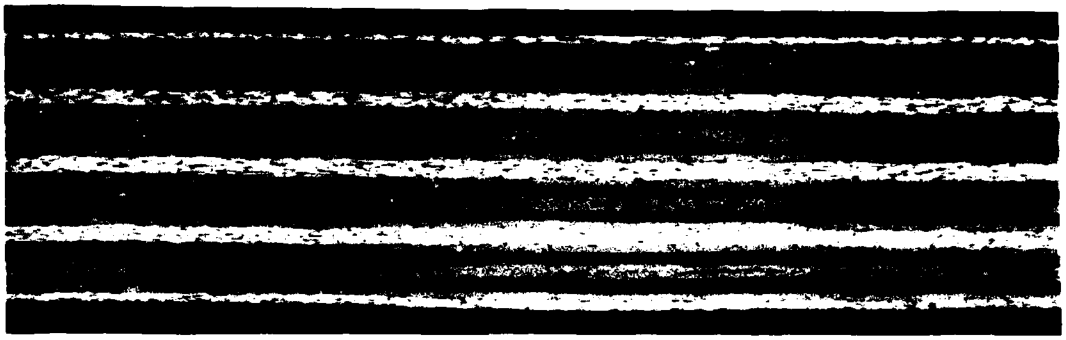
LOCATION: 0.89 IN. DAMAGE LENGTH: 0.419

M22-4-1 10X



M22-4-2 25X

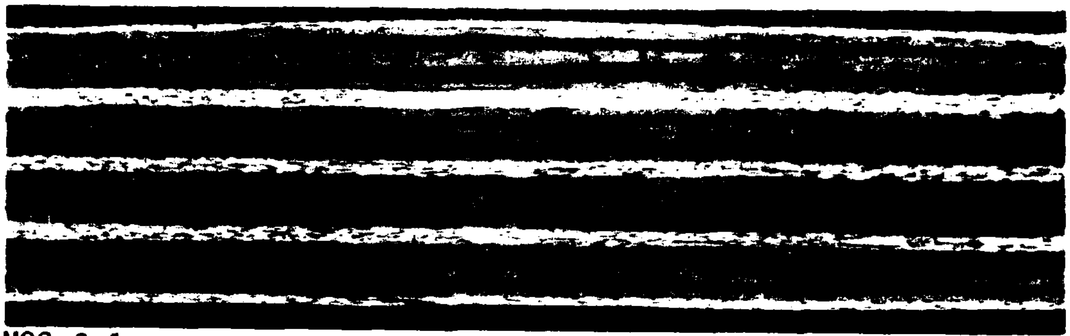
LOCATION: 0.99 IN. DAMAGE LENGTH: 0.620



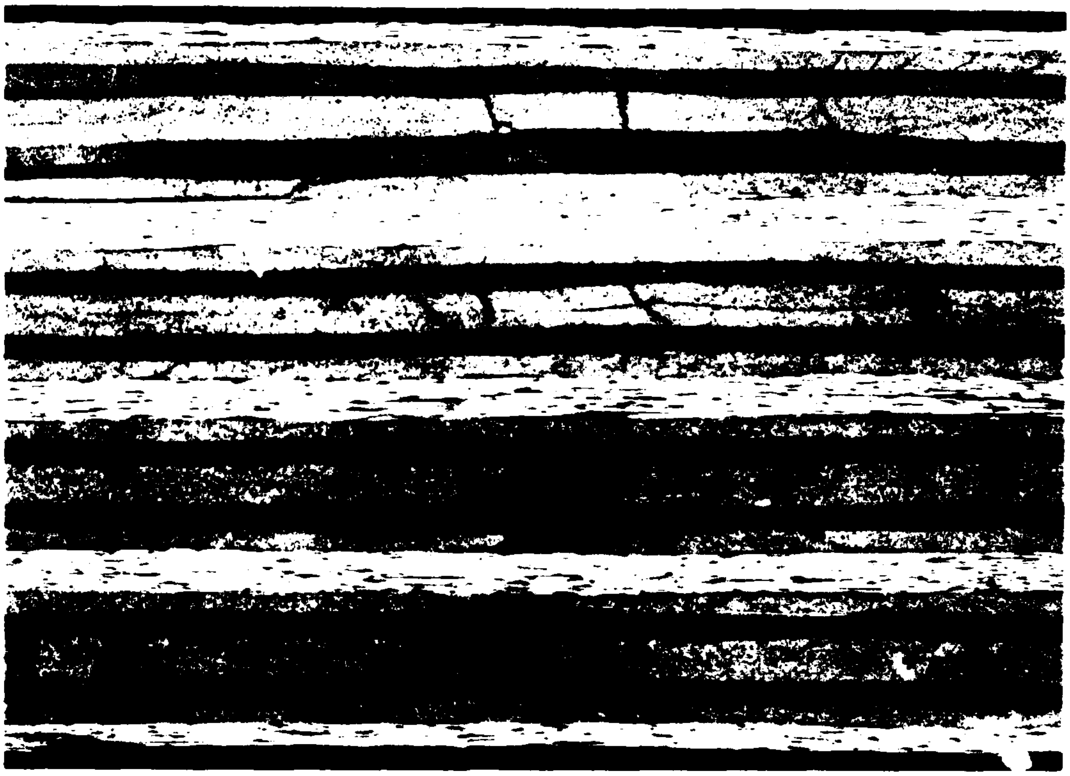
M22-5-1 10X

M22-5-2 25X

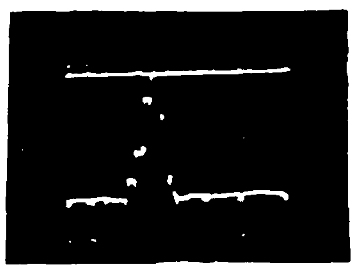
LOCATION: 1.09 IN. DAMAGE LENGTH: 0.836



M22-6-1 10X

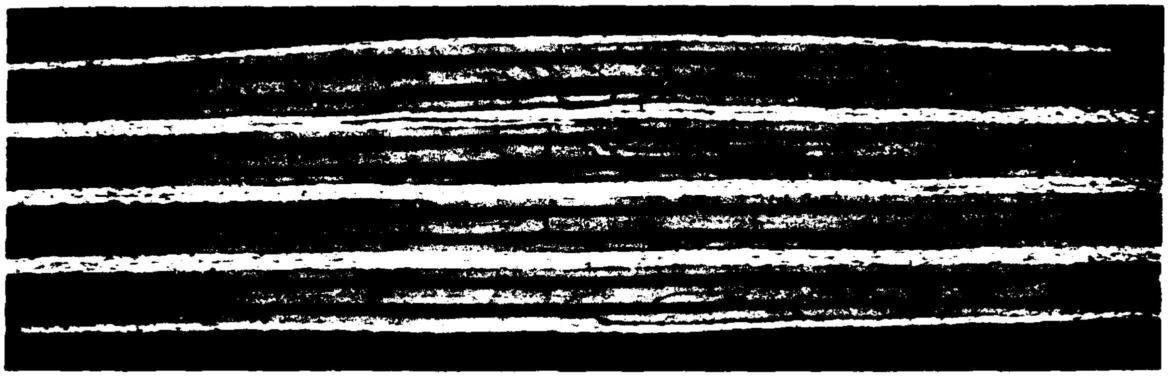


M22-6-2 25X

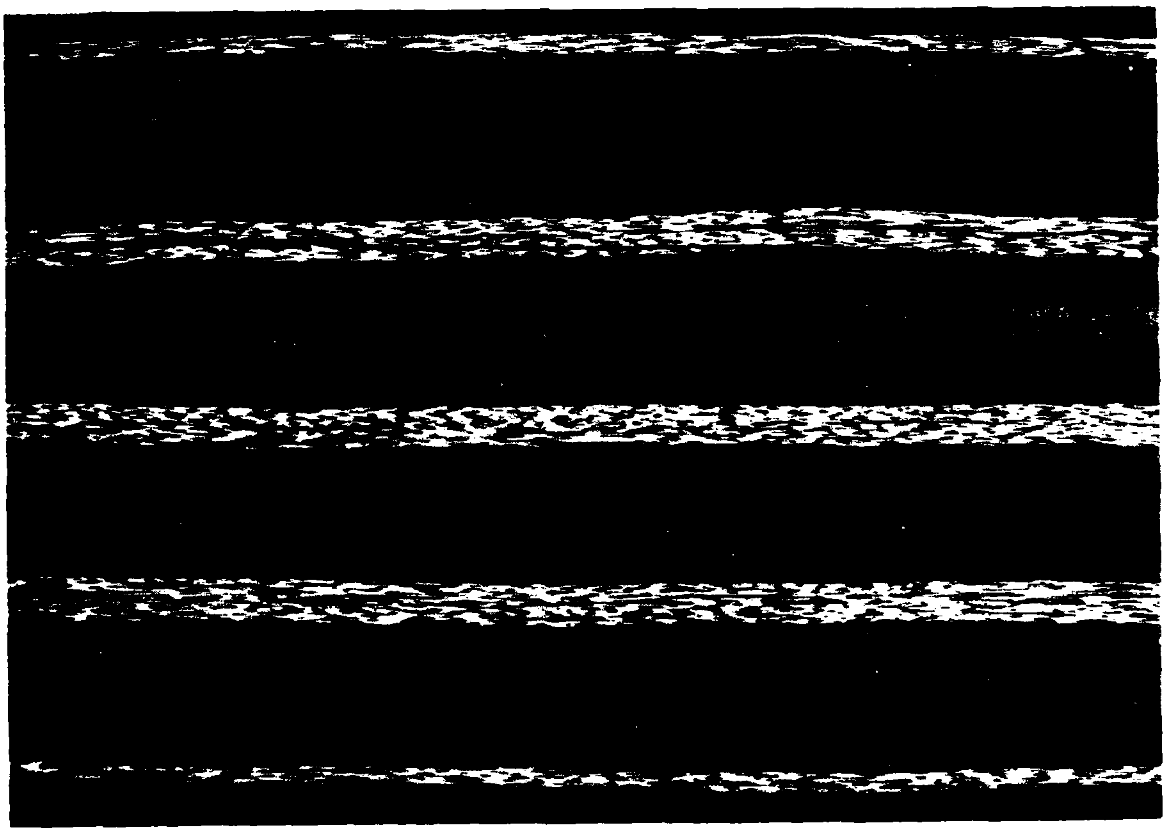


B-SCAN AT 1.16 IN.

LOCATION: 1.19 IN. DAMAGE LENGTH: 0.661

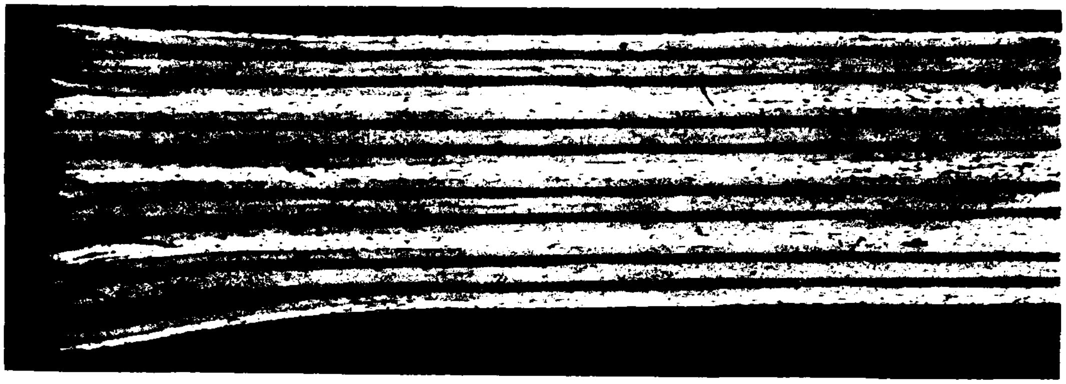


M22-7-1 10X

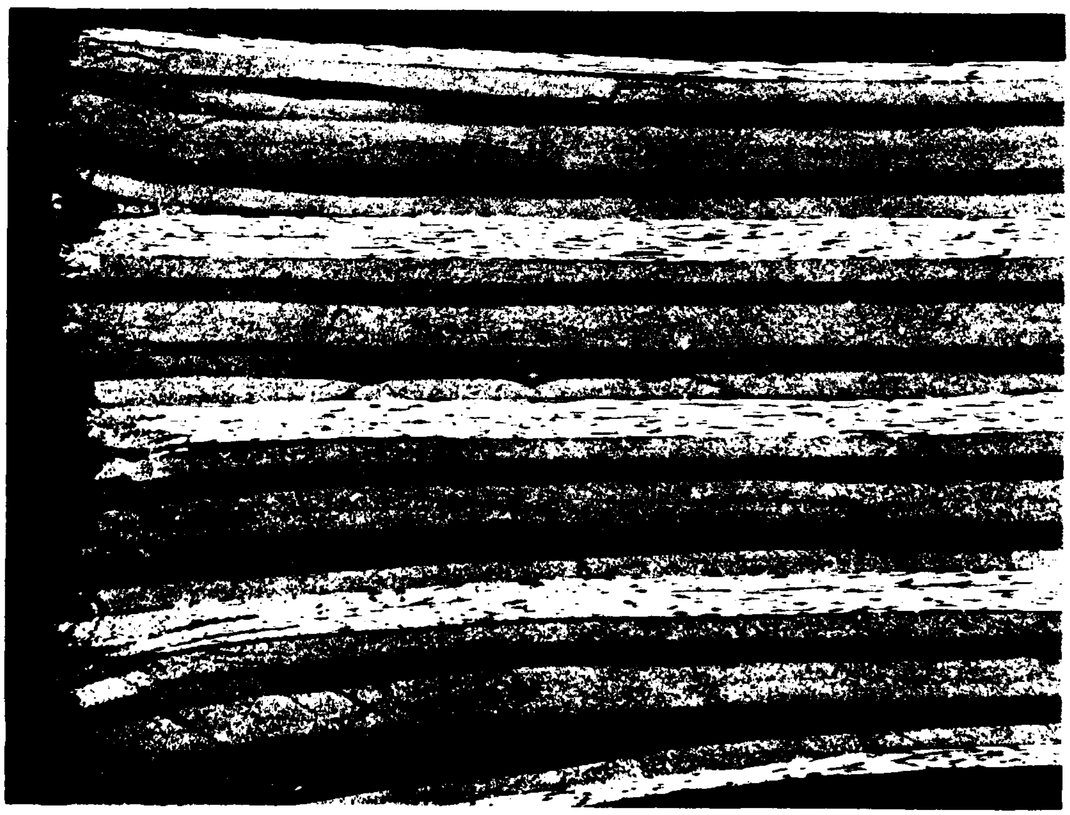


M22-7-2 25X

LOCATION: 1.29 IN. DAMAGE LENGTH: 0.681

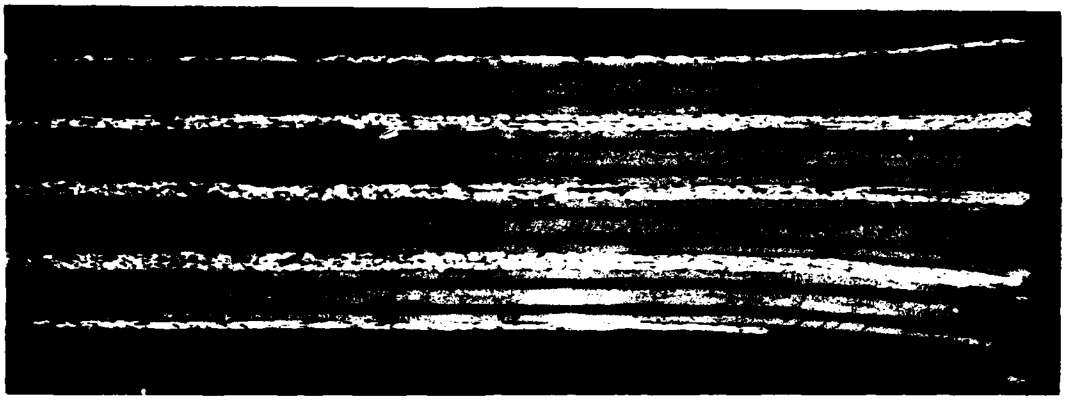


M22-8-1A 10X

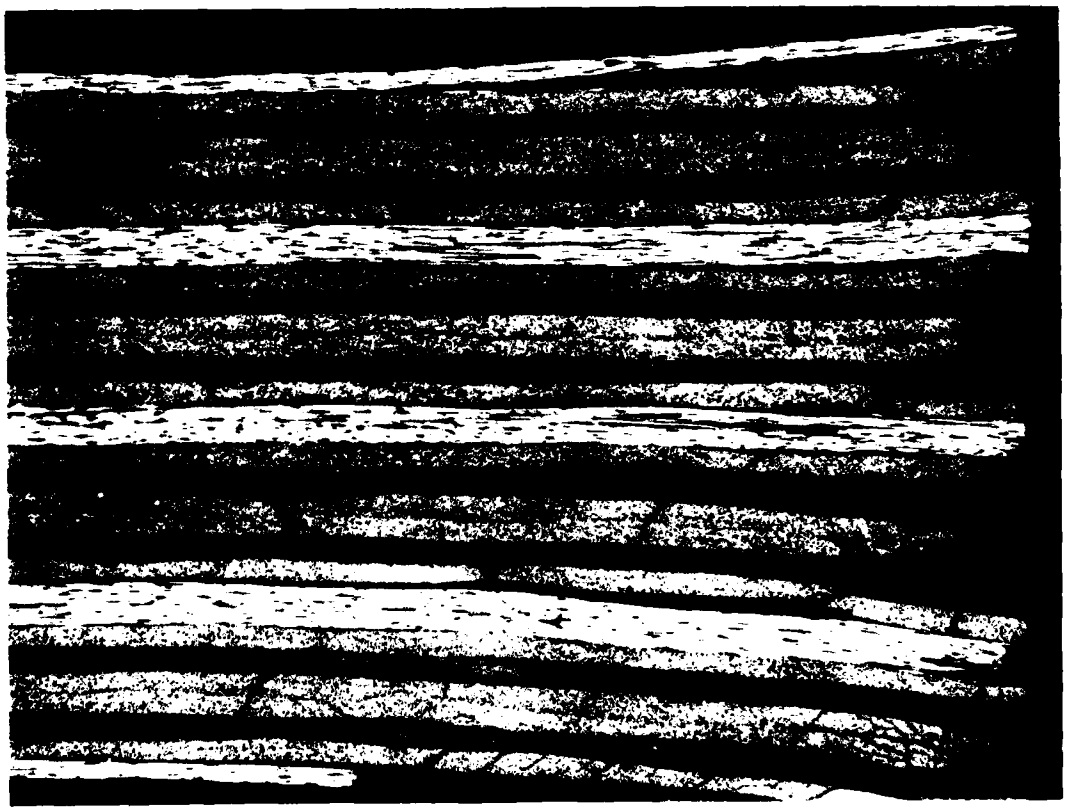


M22-8-1A 25X

LOCATION: 1.39 IN. DAMAGE LENGTH: 0.756

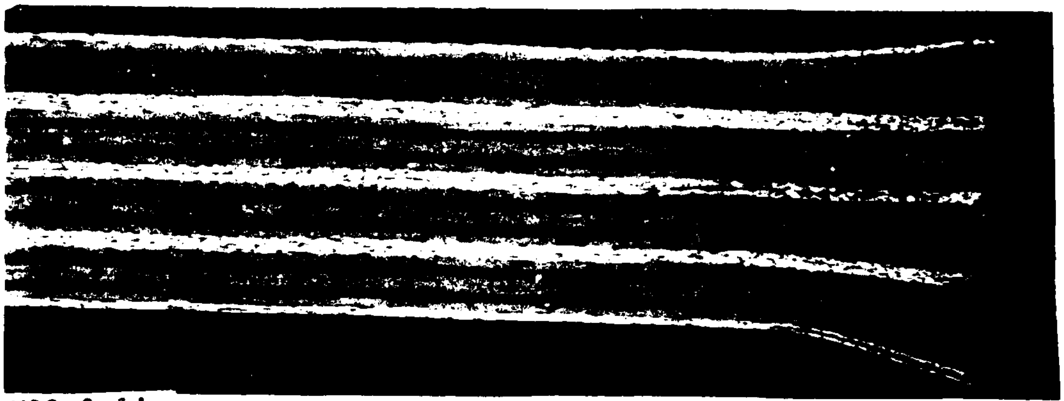


M22-8-2B 10X

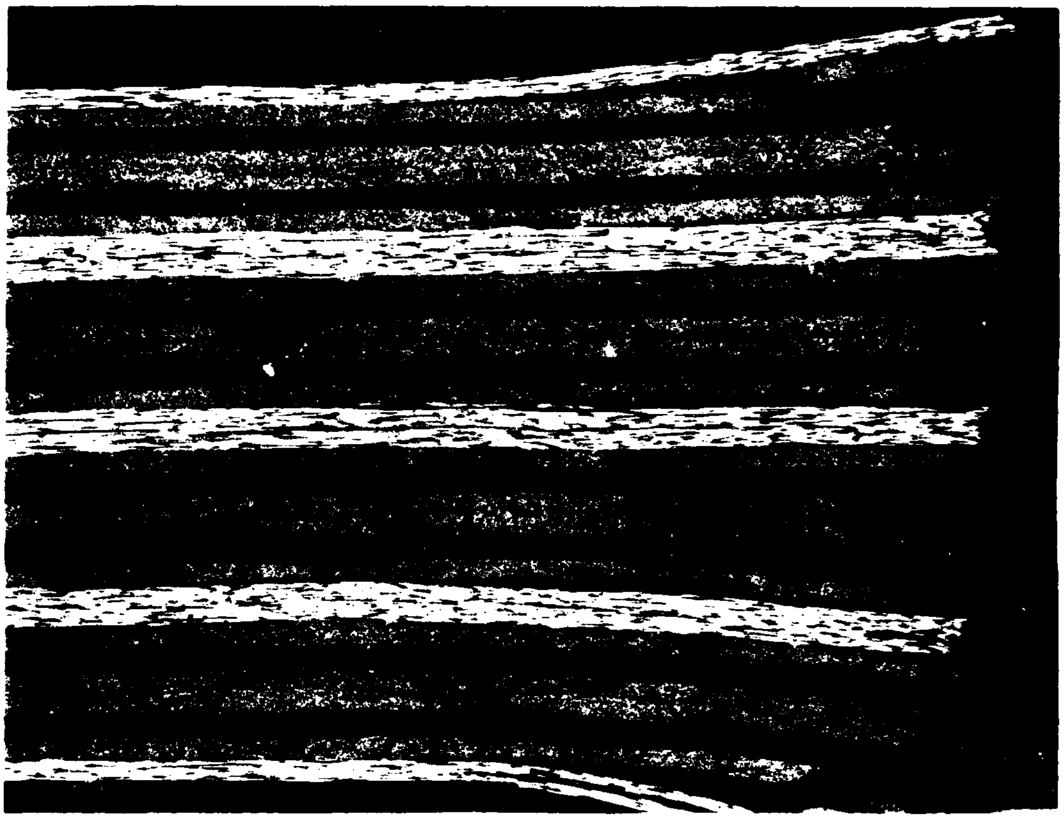


M22-8-2B 25X

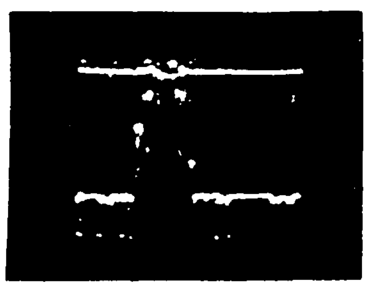
LOCATION: 1.39 IN. DAMAGE LENGTH: 0.756



M22-9-1A 10X



M22-9-2A 25X

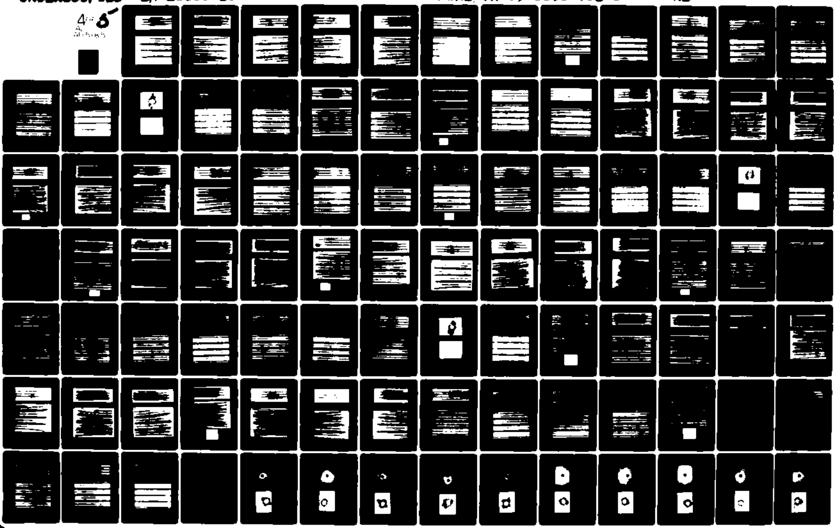


B-SCAN AT CENTER

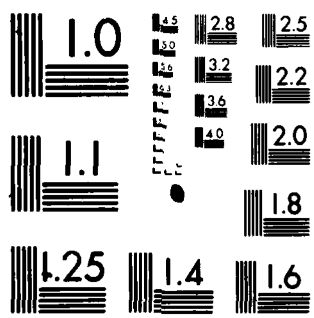
LOCATION: [illegible] IN. DAMAGE LENGTH: [illegible]

AD-A115 185 LOCKHEED-CALIFORNIA CO BURBANK F/G 11/4
ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC--ETC(U)
JUL 81 K N LAURAITIS, J T RYDER, D E PETTIT F33615-77-C-3084
UNCLASSIFIED LR-28360-19 AFWAL-TR-79-3095-VOL-3 NL

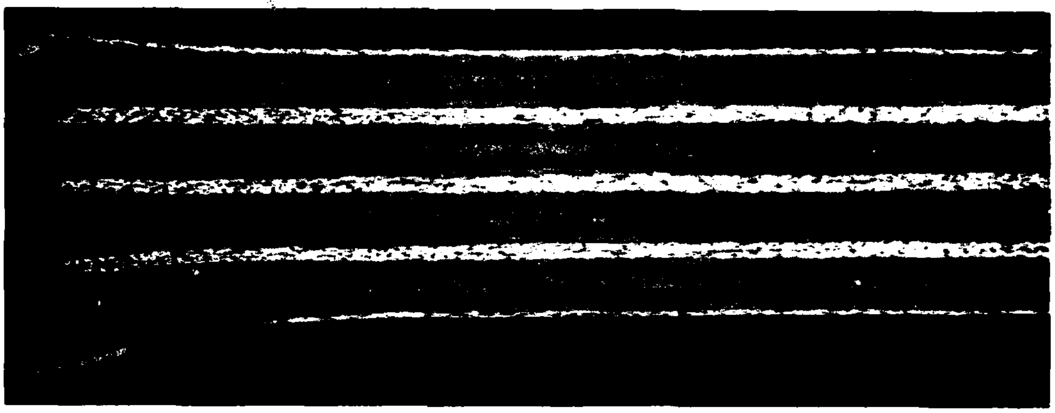
4 of 5



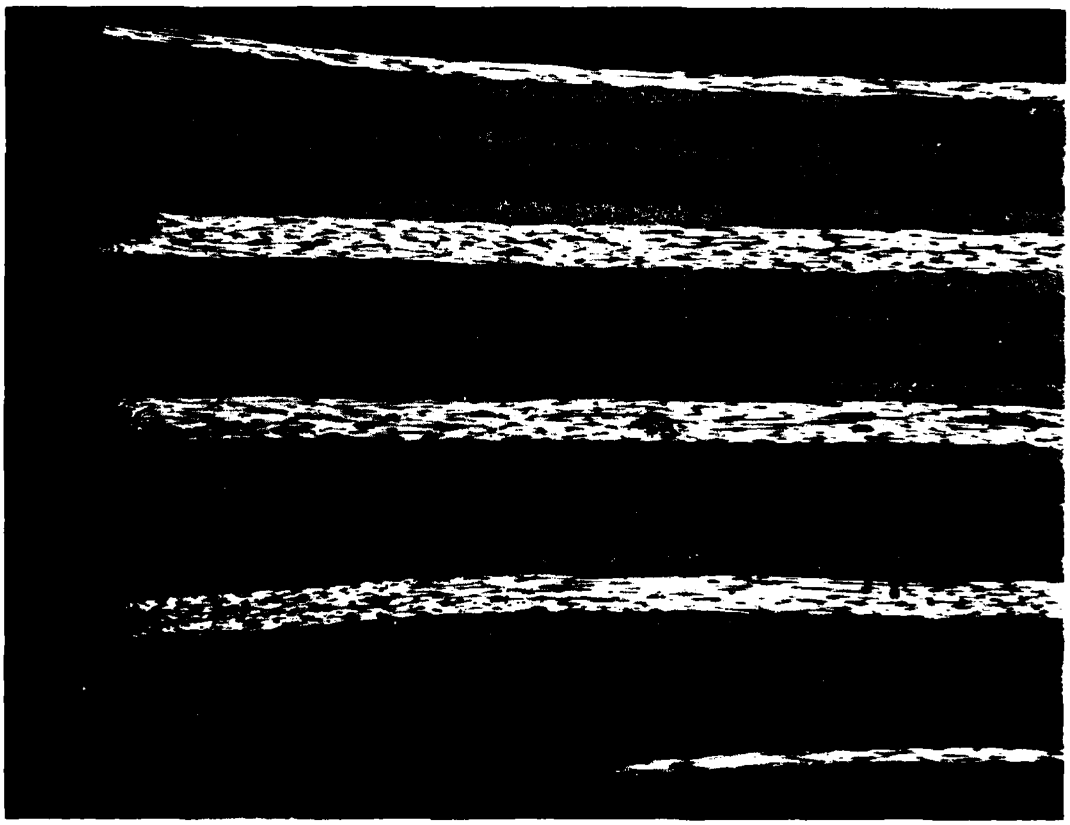
11518



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

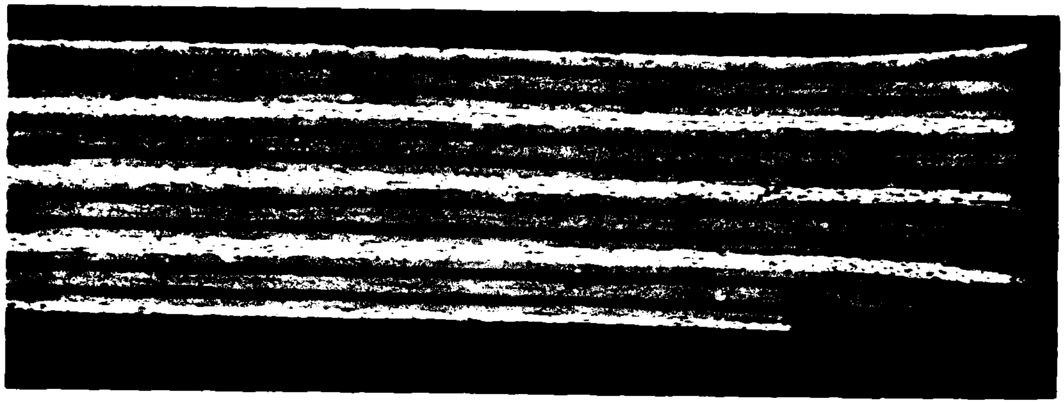


M22-9-1B 10X

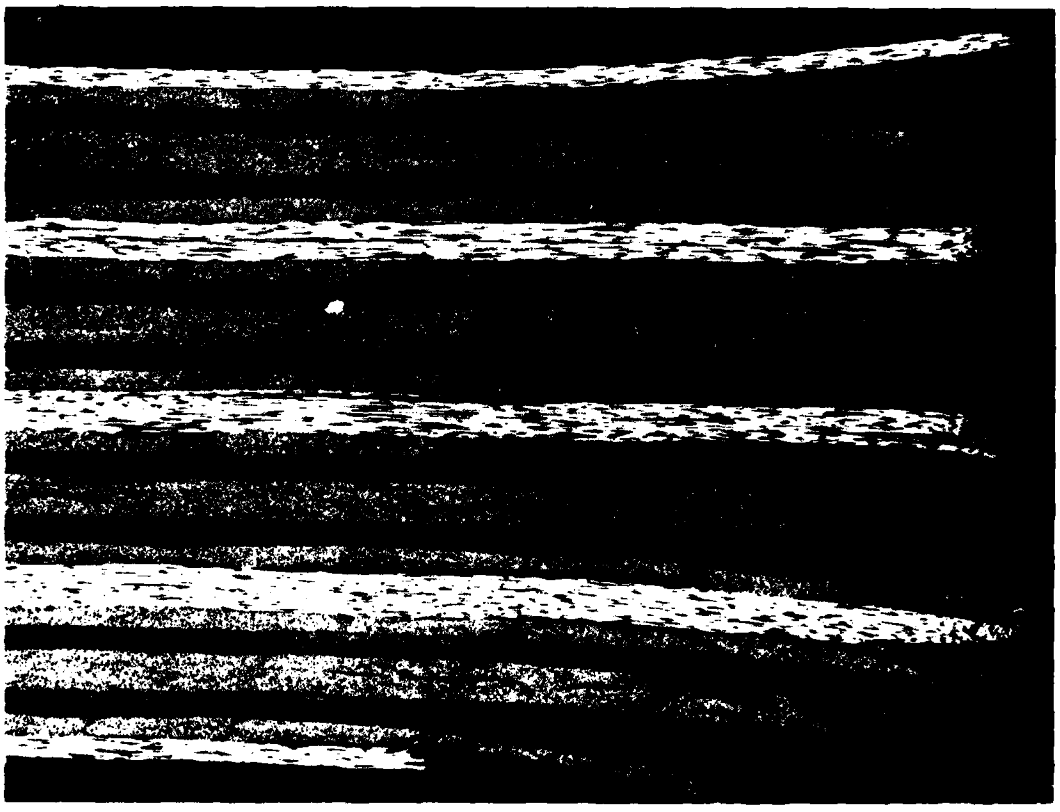


M22-9-2B 25X

LOCATION: 1.49 IN. DAMAGE LENGTH: 0.780

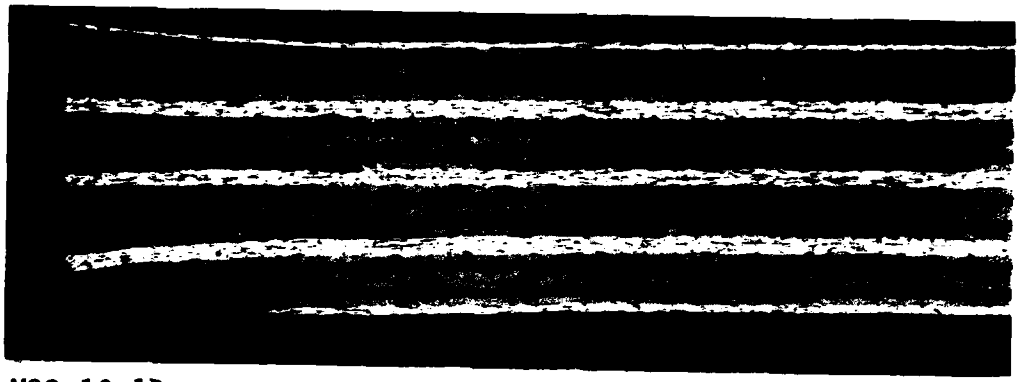


M22-10-1A 10X

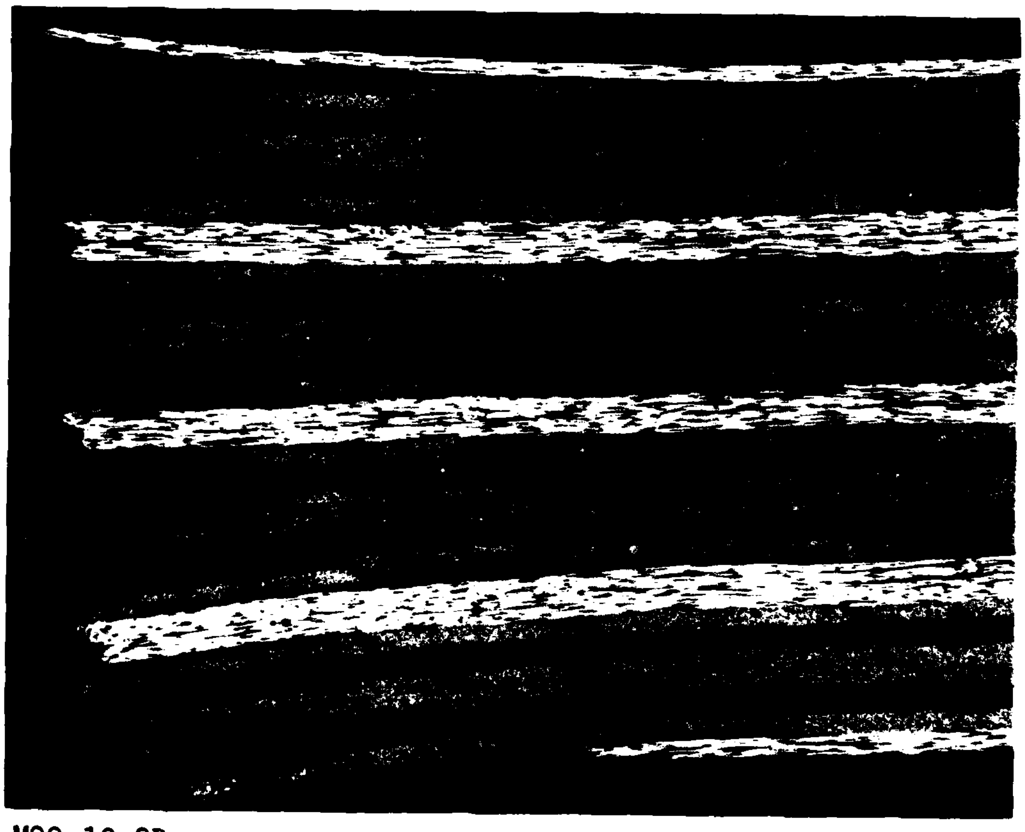


M22-10-2A 25X

LOCATION: 1.59 IN. DAMAGE LENGTH: 0.793

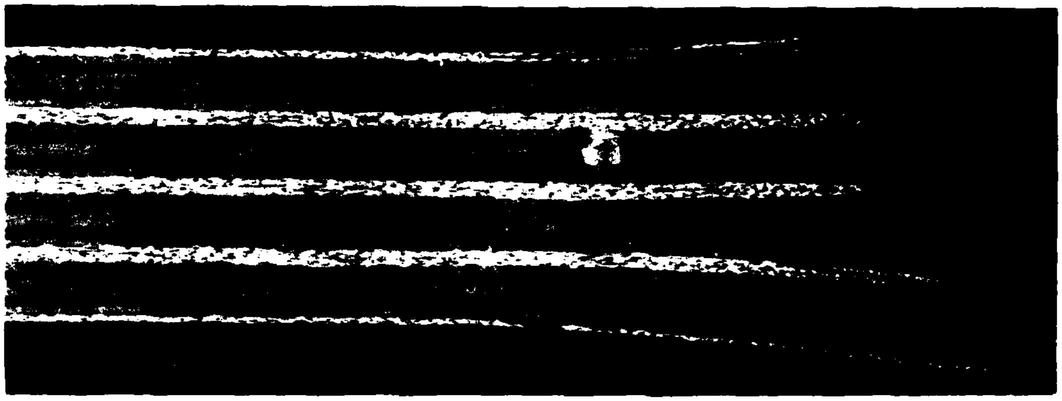


M22-10-1B 10X

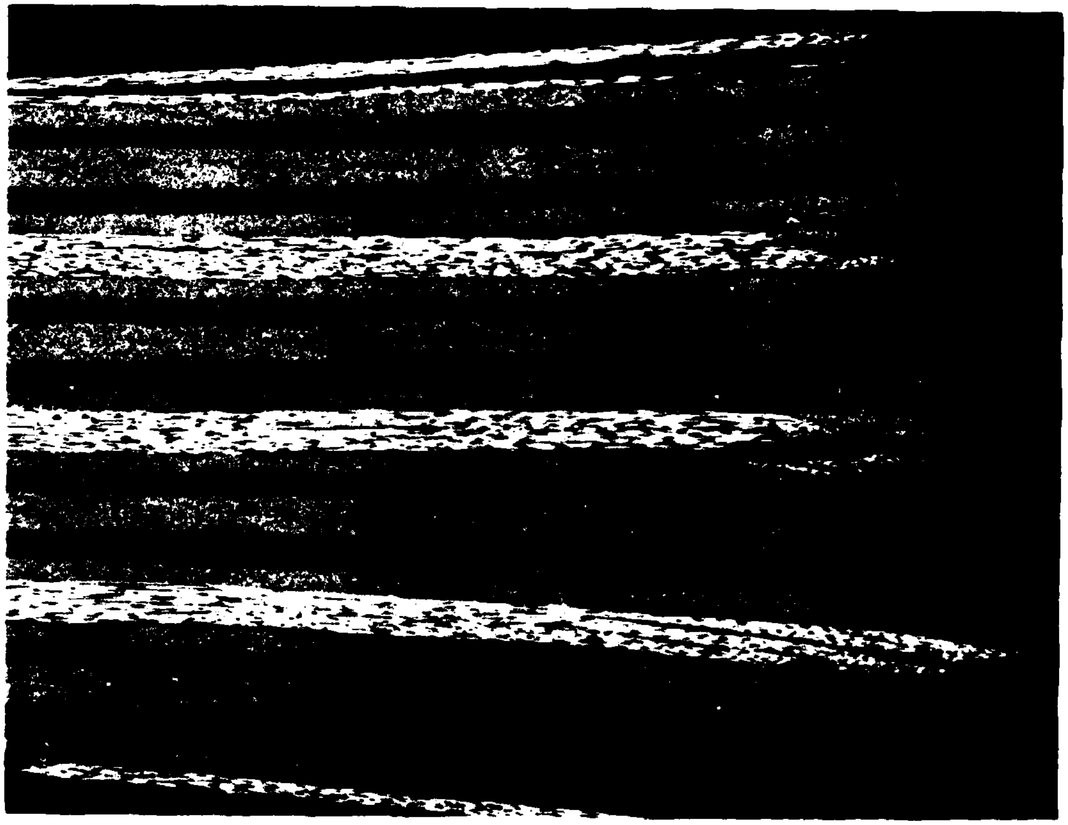


M22-10-2B 25X

LOCATION: 1.59 IN. DAMAGE LENGTH: 0.793

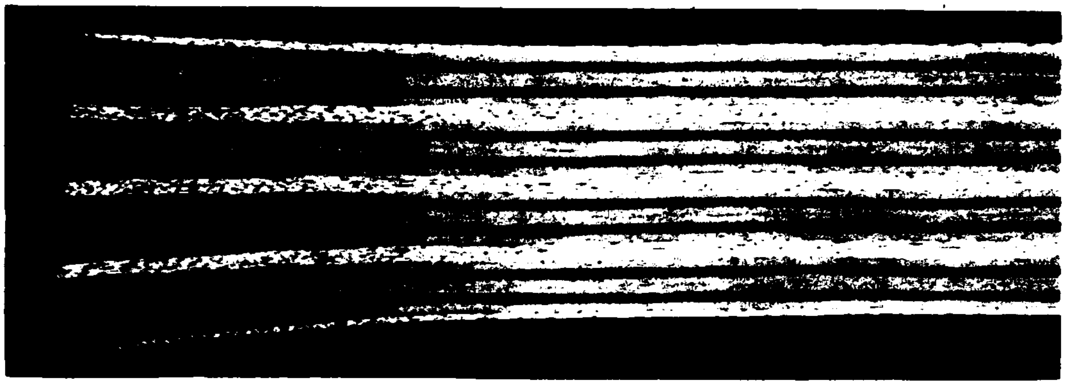


M22-11-1A 10X

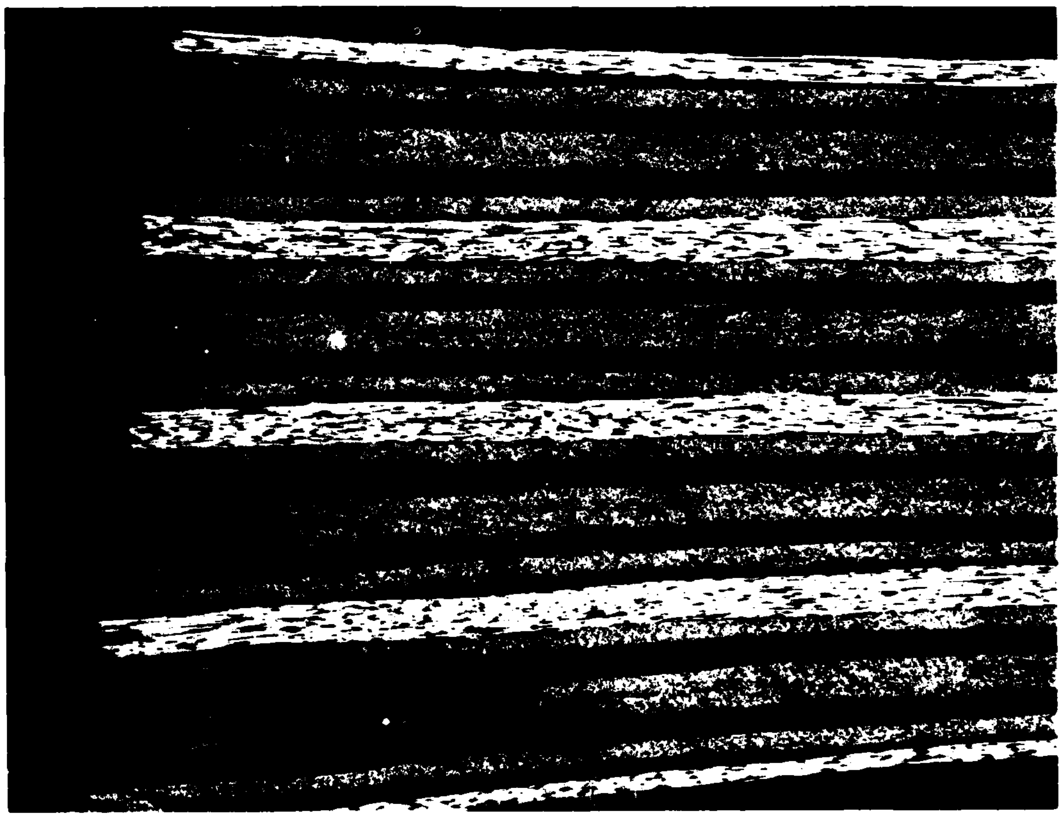


M22-11-2A 25X

LOCATION: 1.69 IN. DAMAGE LENGTH: 0.726

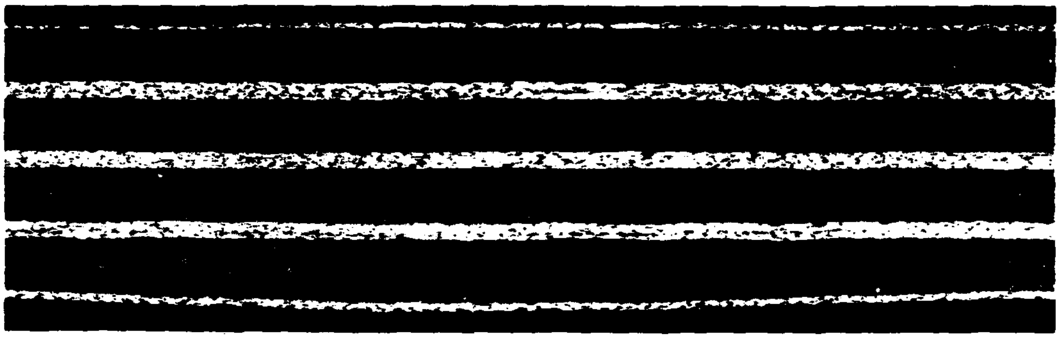


M22-11-1B 10X

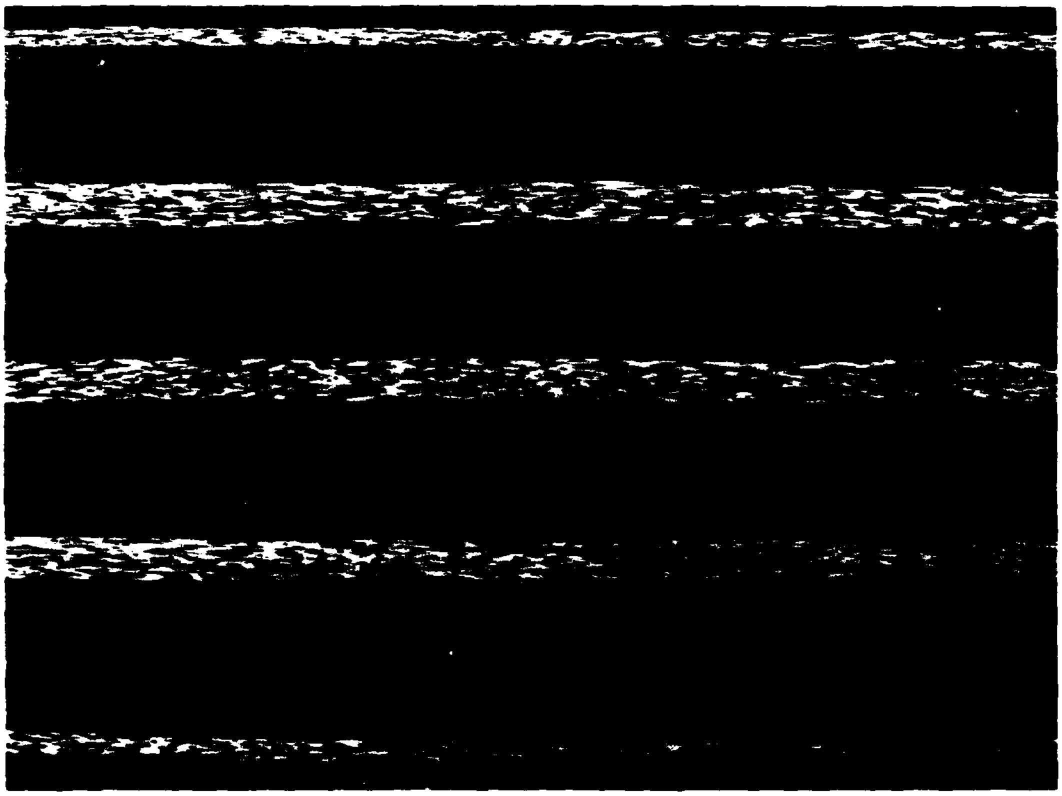


M22-1J-2P 25X

LOCATION: 1.69 IN. DAMAGE LENGTH: 0.726

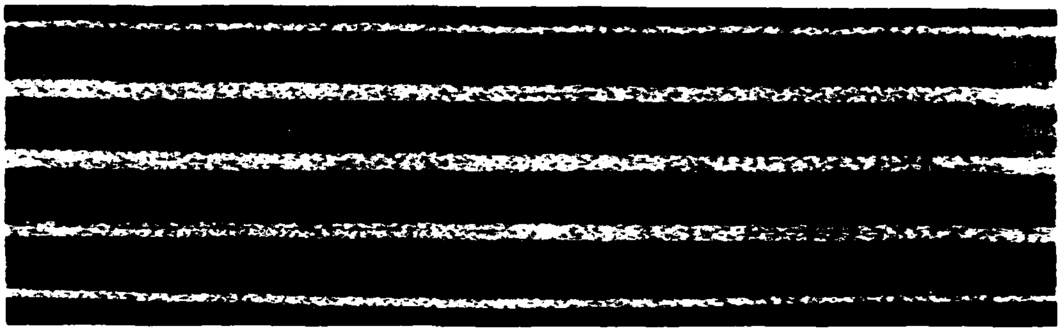


M22-12-1 10X

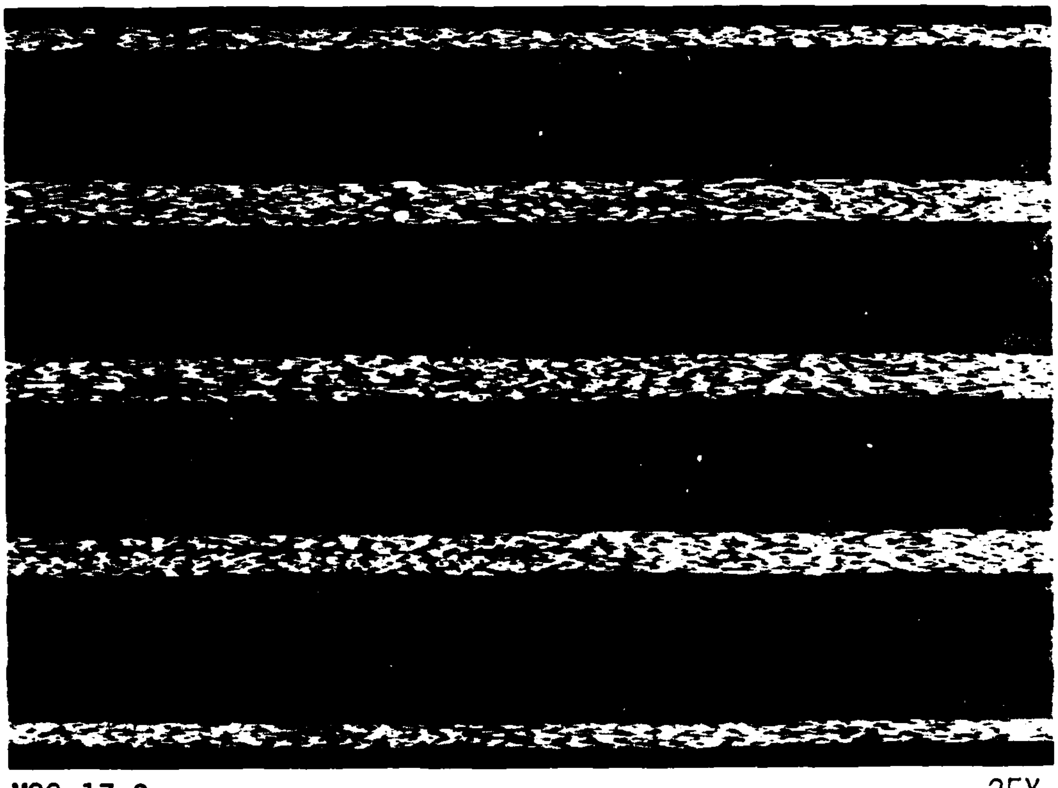


M22-12-2 25X

LOCATION: 1.79 IN. DAMAGE LENGTH: 0.754



M22-13-1 10X

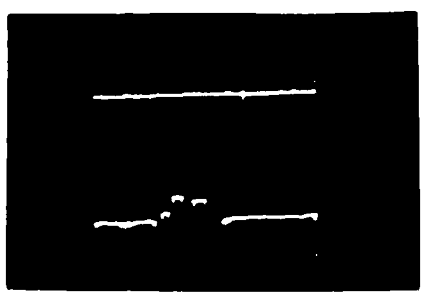


M22-13-2 25X

LOCATION: 1.89 IN. DAMAGE LENGTH: 0.689

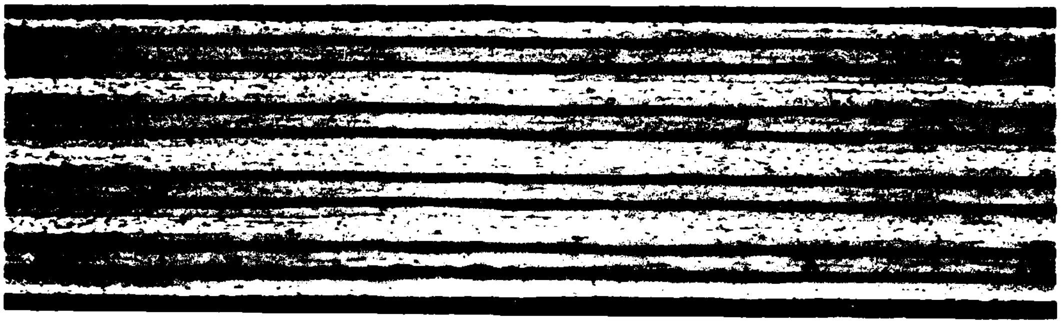
M22-14-1 10X

M22-14-2 25X

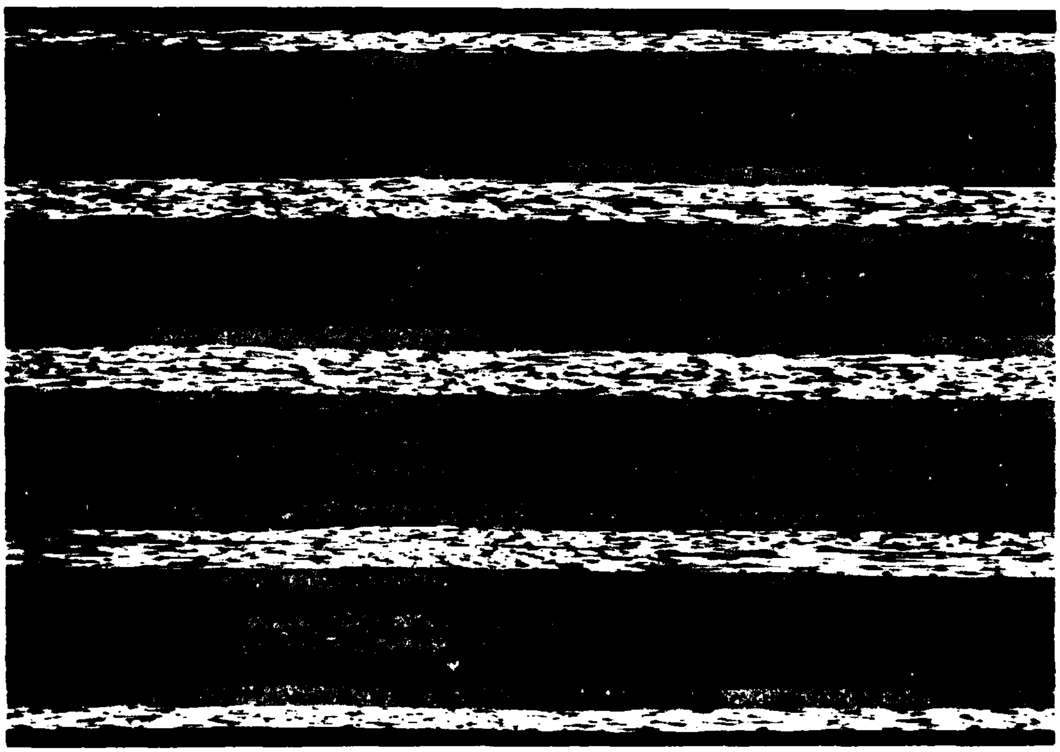


B-SCAN AT 1.95 IN.

LOCATION: 1.99 IN. DAMAGE LENGTH: 0.641

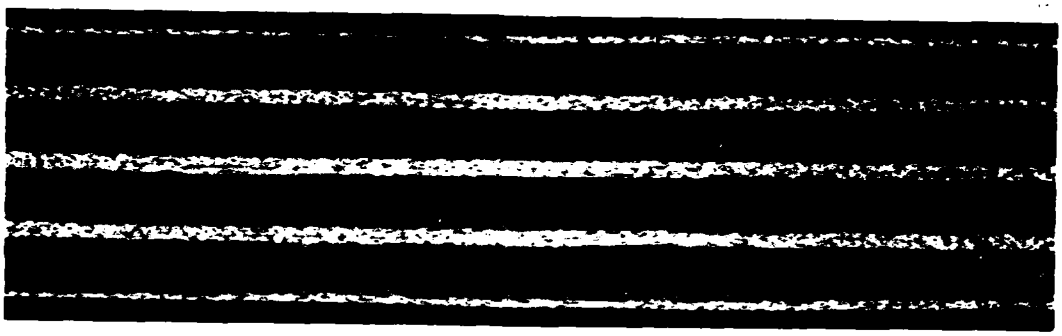


M22-15-1 10X

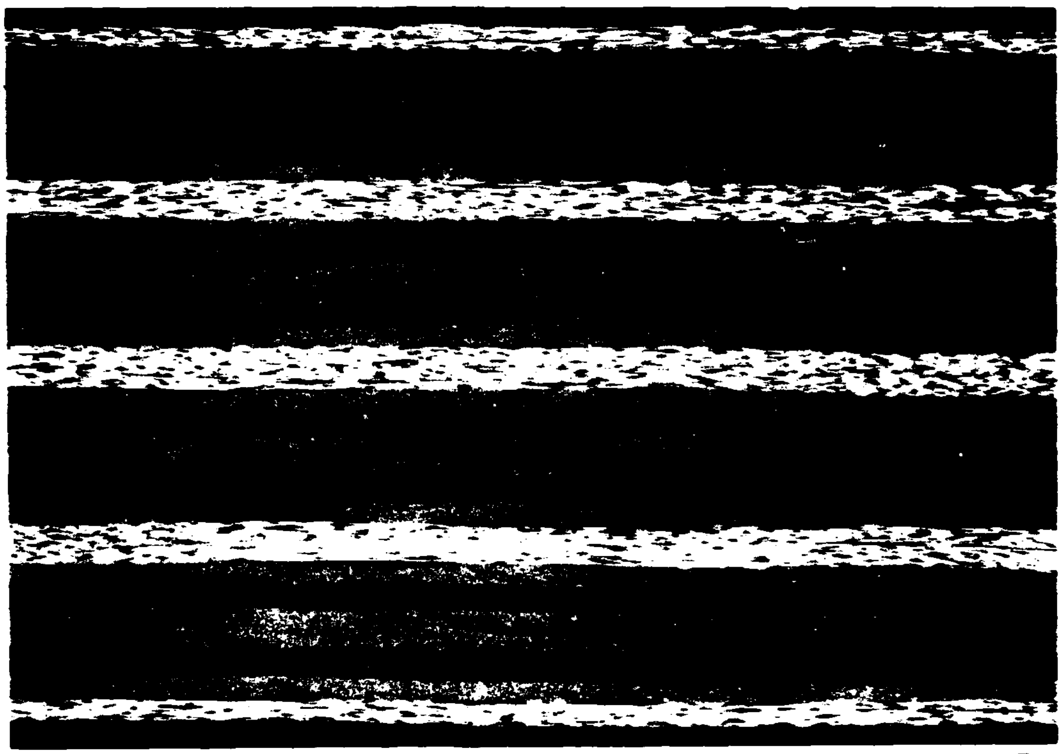


M22-15-2 25X

LOCATION: 2.09 IN. DAMAGE LENGTH: 0.554

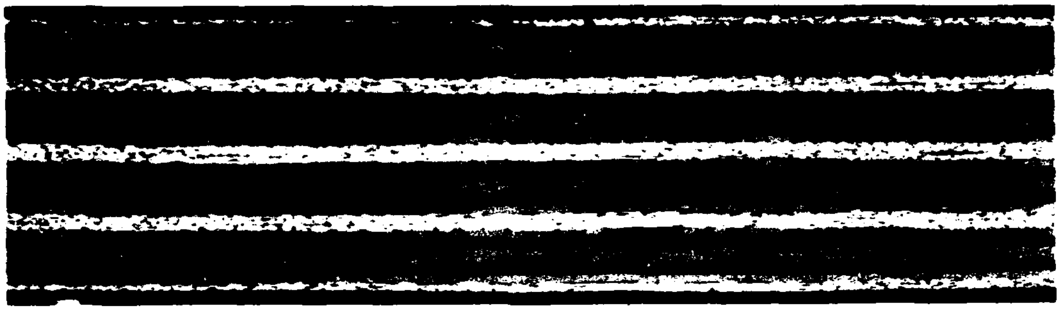


M22-16-1A 10X

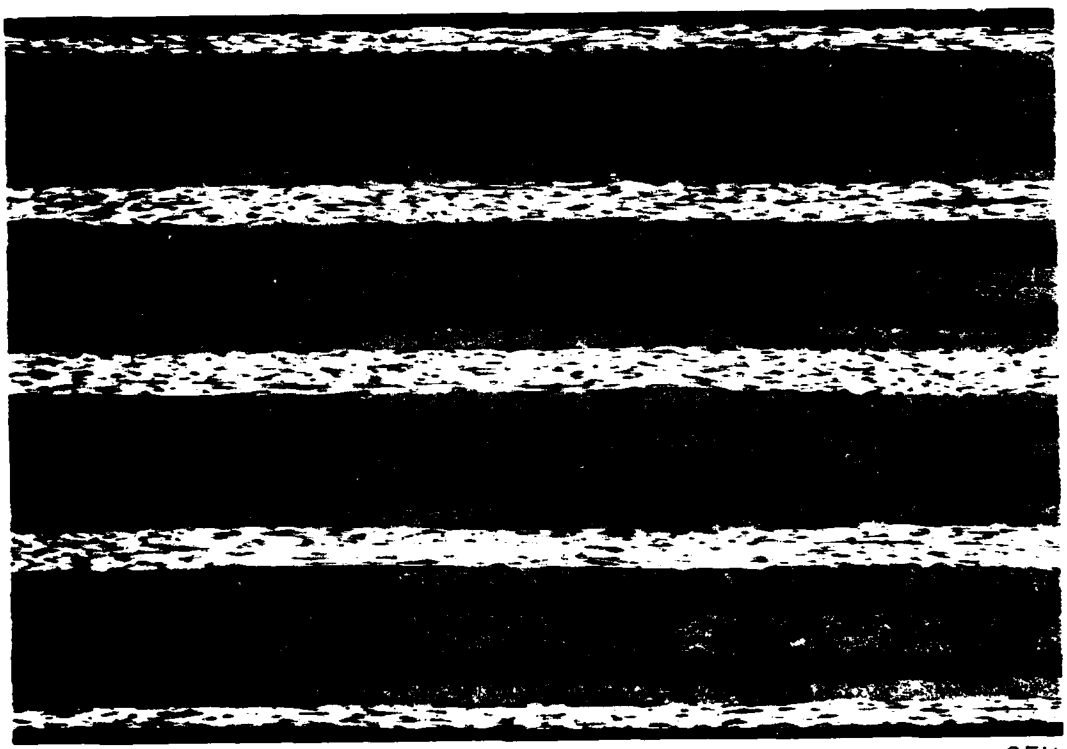


M22-16-2A 25X

LOCATION: 2.19 IN. DAMAGE LENGTH: 0.390

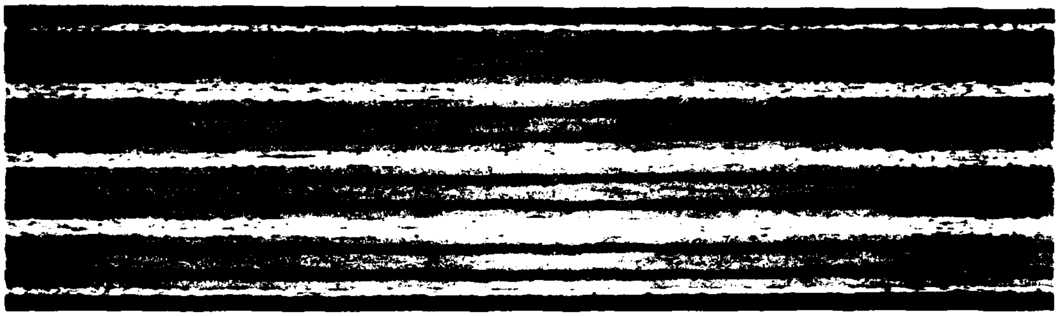


M22-16-1B 10X

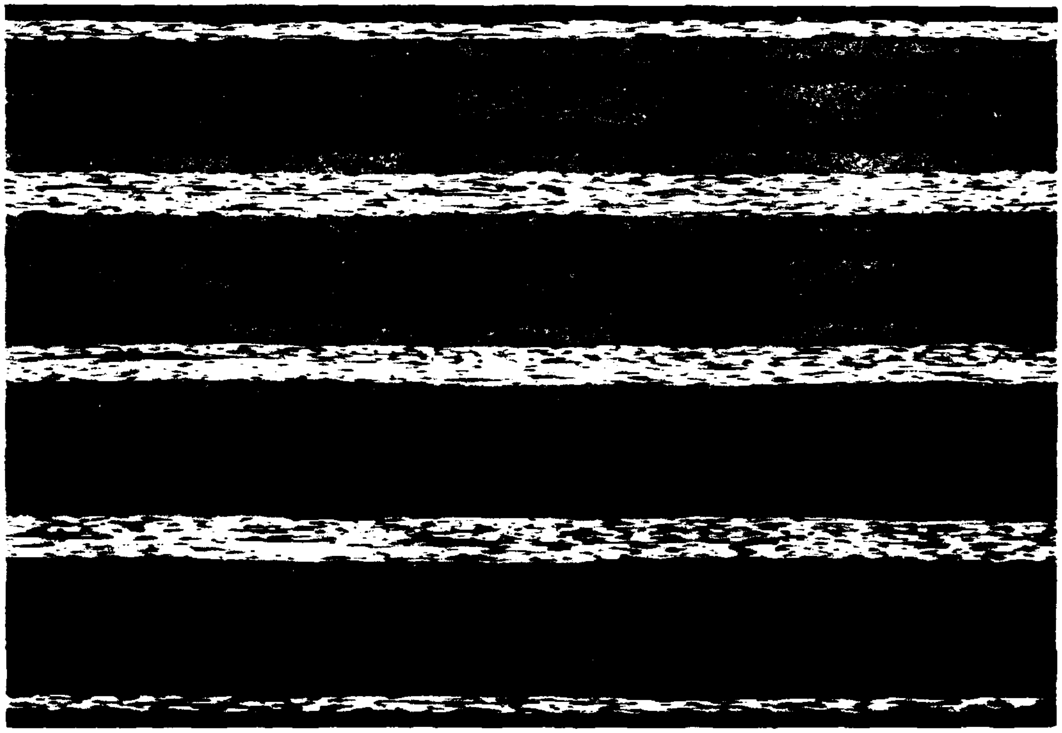


M22-16-2B 25X

LOCATION: 2.19 IN. DAMAGE LENGTH: 0.390

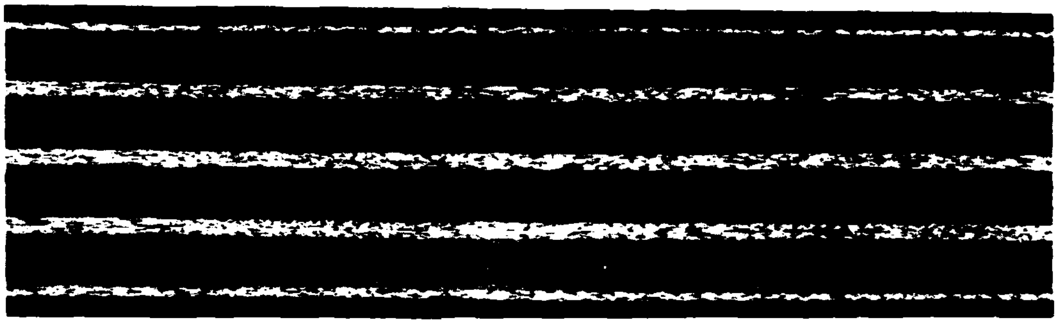


M22-17-1 10X

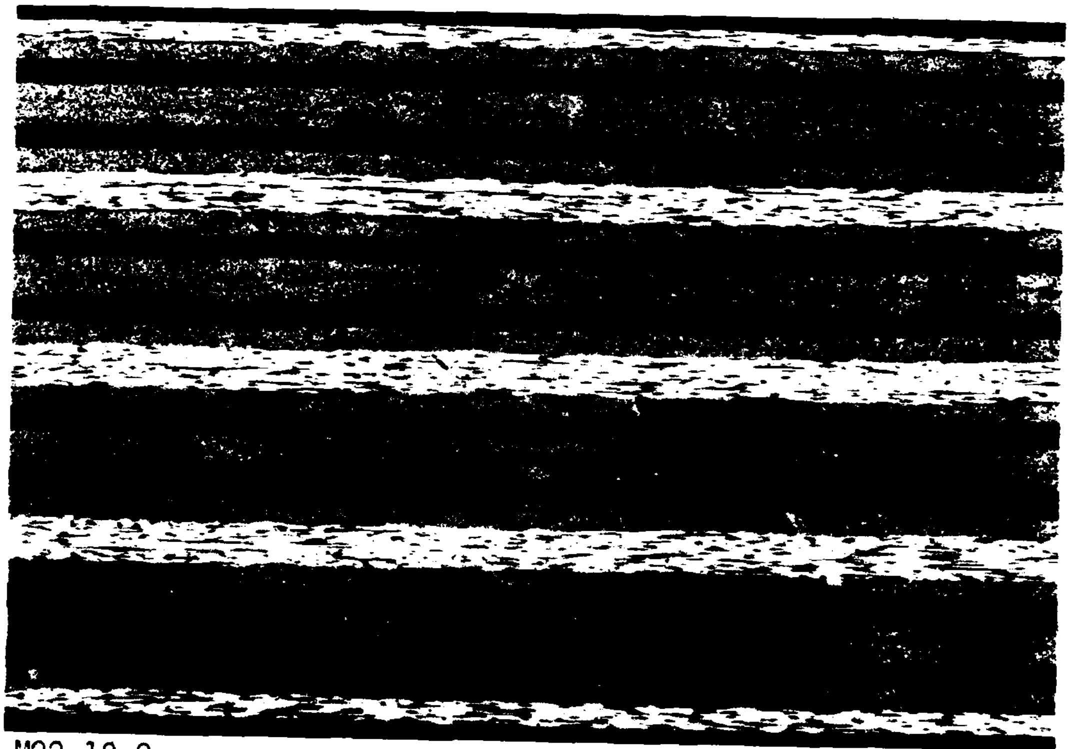


M22-17-2 25X

LOCATION: 2.29 IN. DAMAGE LENGTH: 0.325

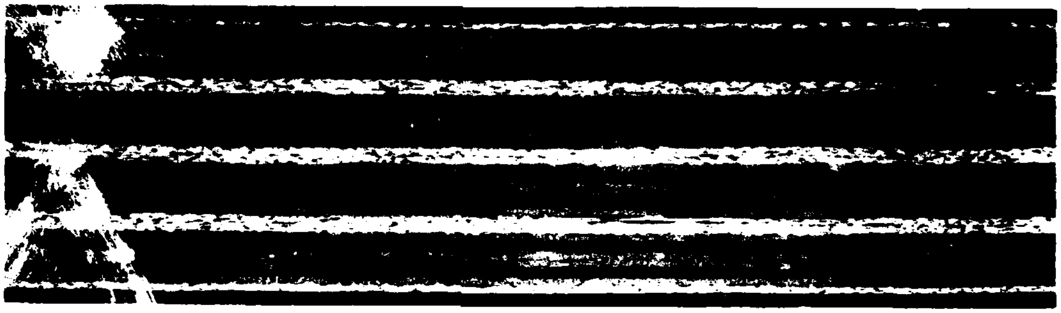


M22-18-1 10X

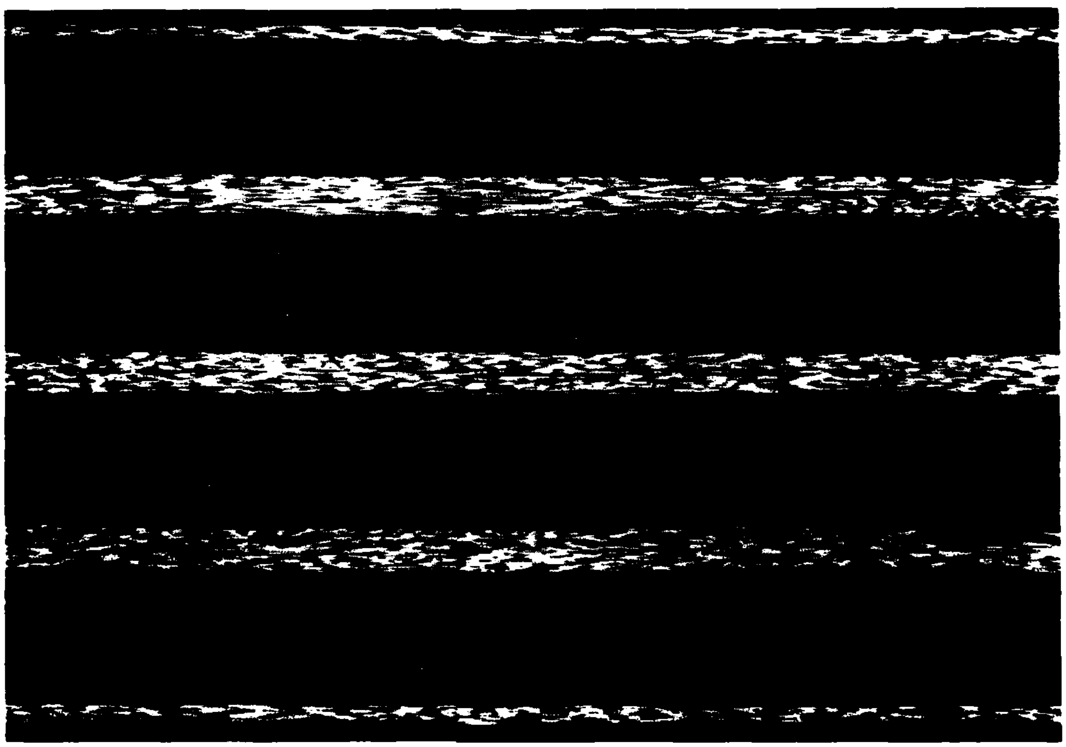


M22-18-2 25X

LOCATION: 2.39 IN. DAMAGE LENGTH: 0.115

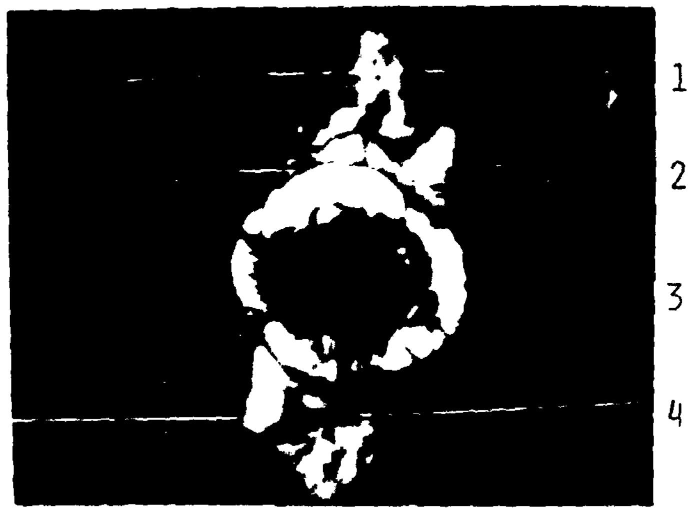


M22-19-1 10X



M22-19-2 25X

LOCATION: 2.49 IN. DAMAGE LENGTH: No Damage

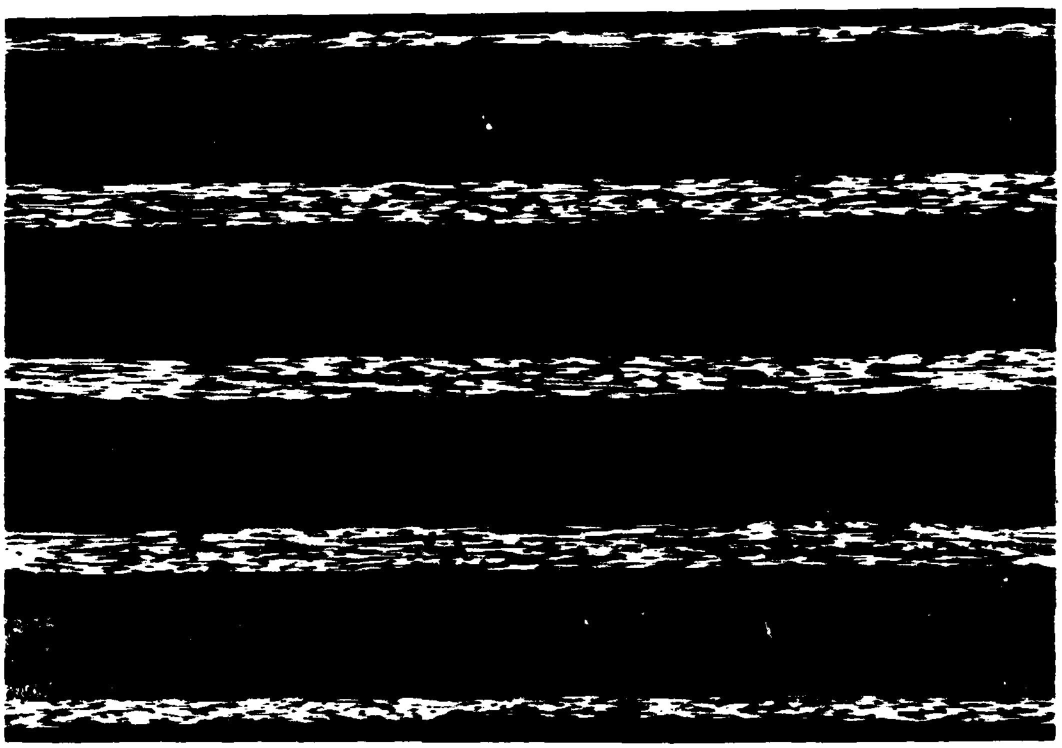


C-SCAN

CUMULATIVE B-SCAN

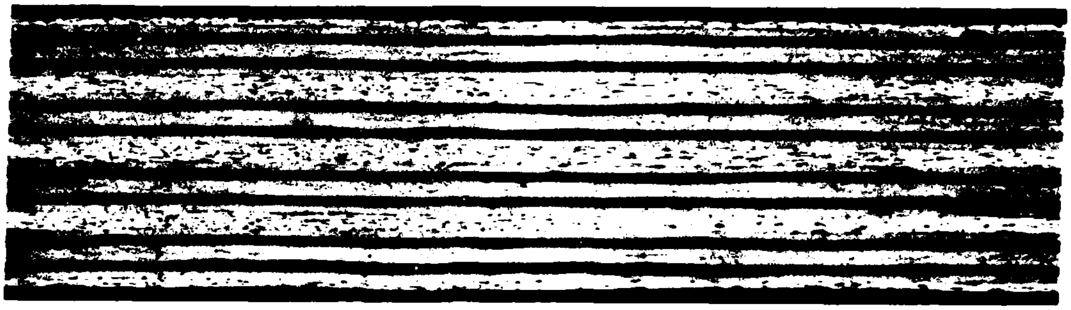
32-PLY SPEC: RC-23 N_3 = 10,000 CYCLES

R23-1-1 10X

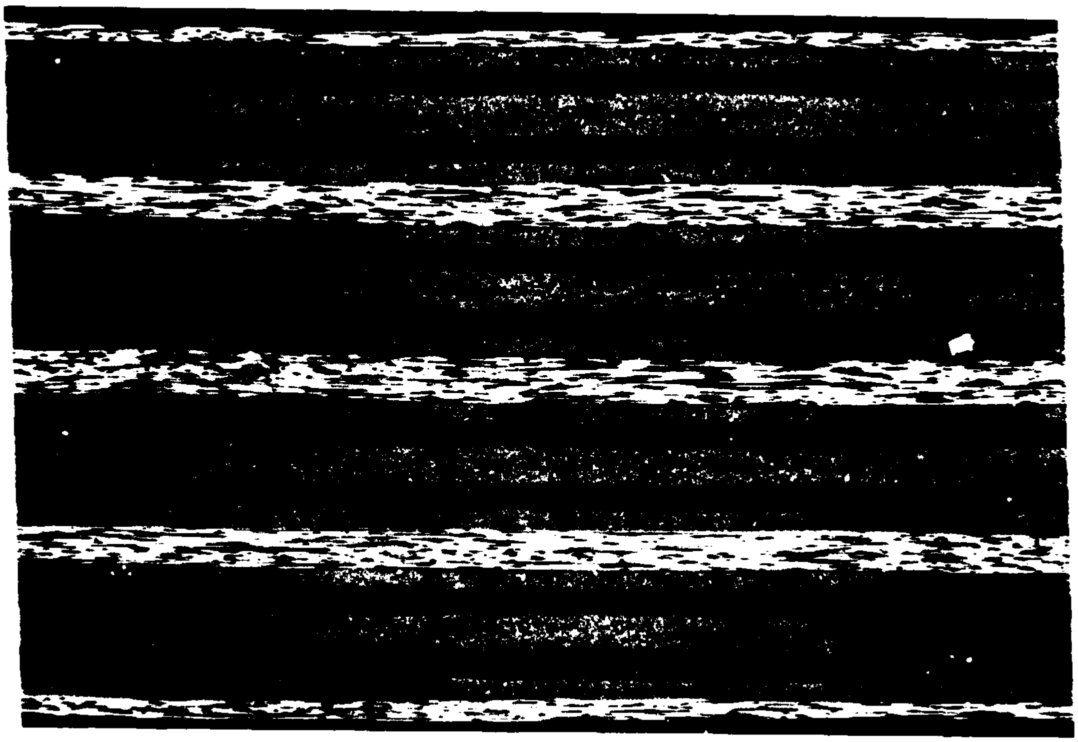


R23-1-2 25X

LOCATION: 0.61 IN. DAMAGE LENGTH: 0.237



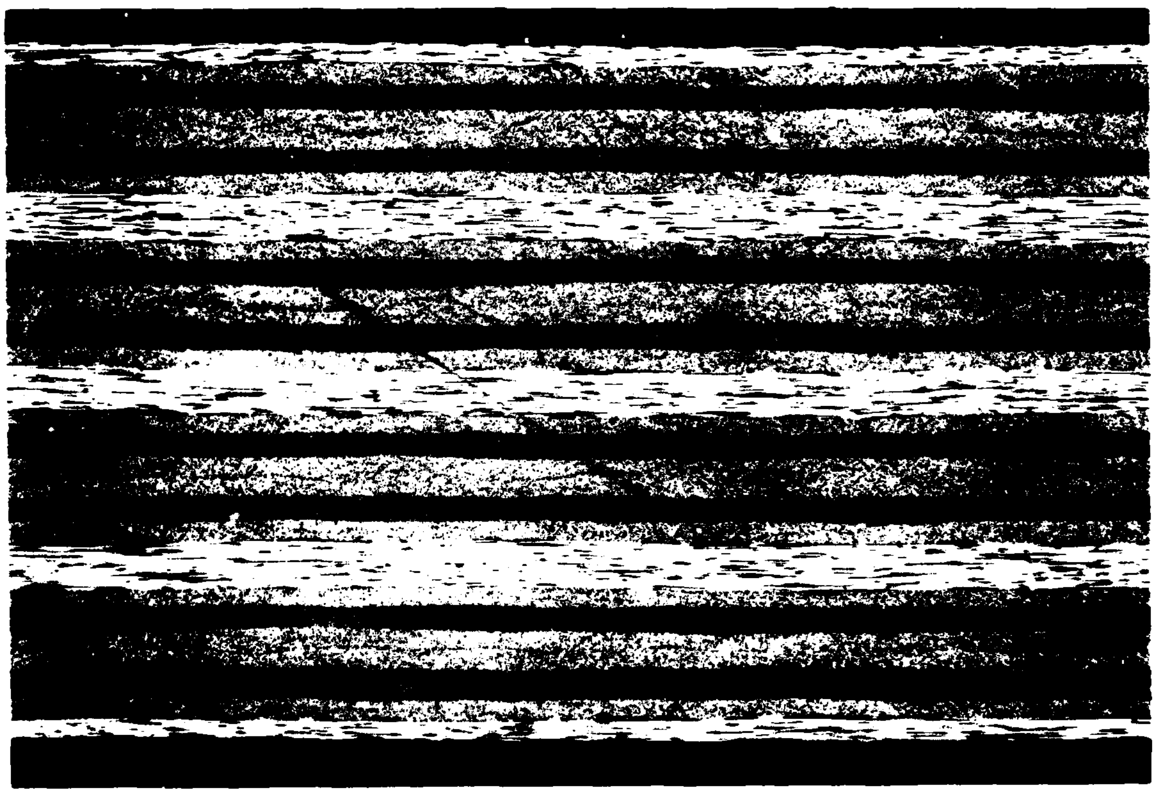
R23-2-1 10X



R23-2-2 25X

LOCATION: 0.71 IN. DAMAGE LENGTH: 0.379

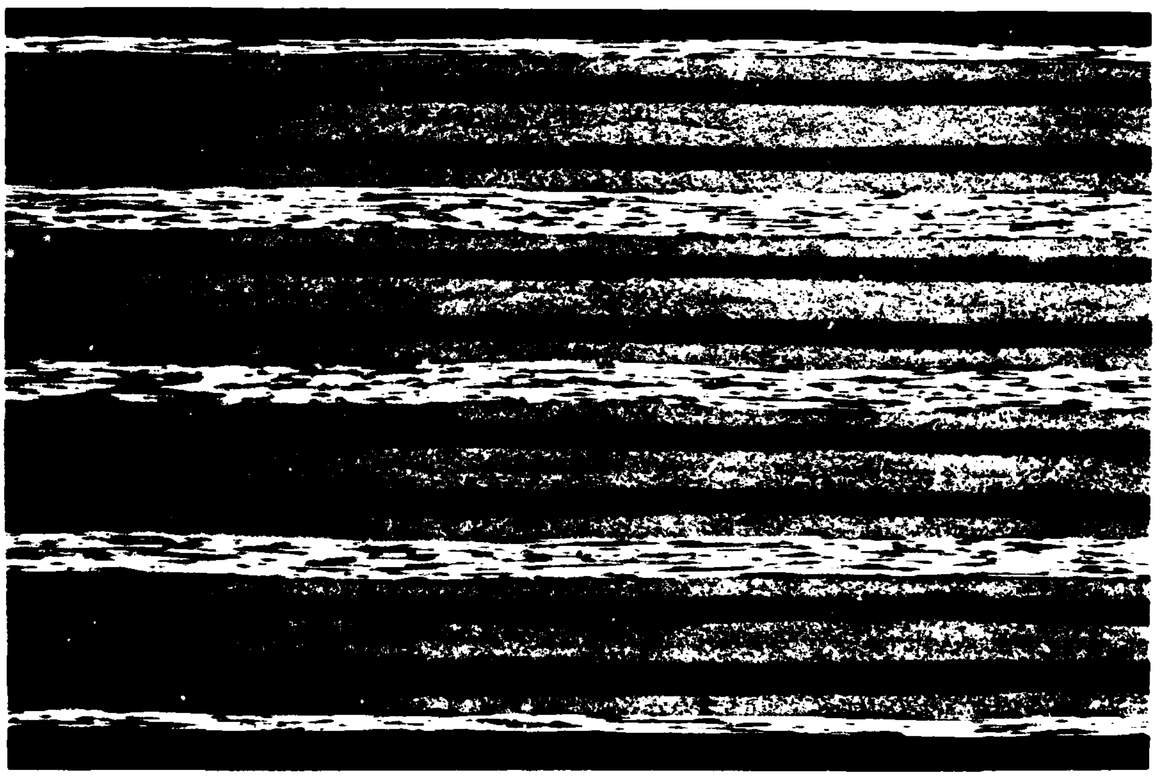
R23-3-1 10X



R23-3-2 25X

LOCATION: 0.81 DAMAGE LENGTH: 0.438

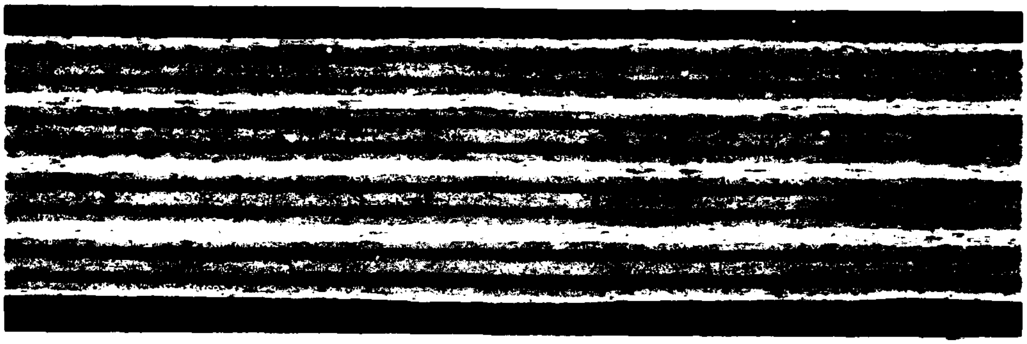
R23-4-1 10X



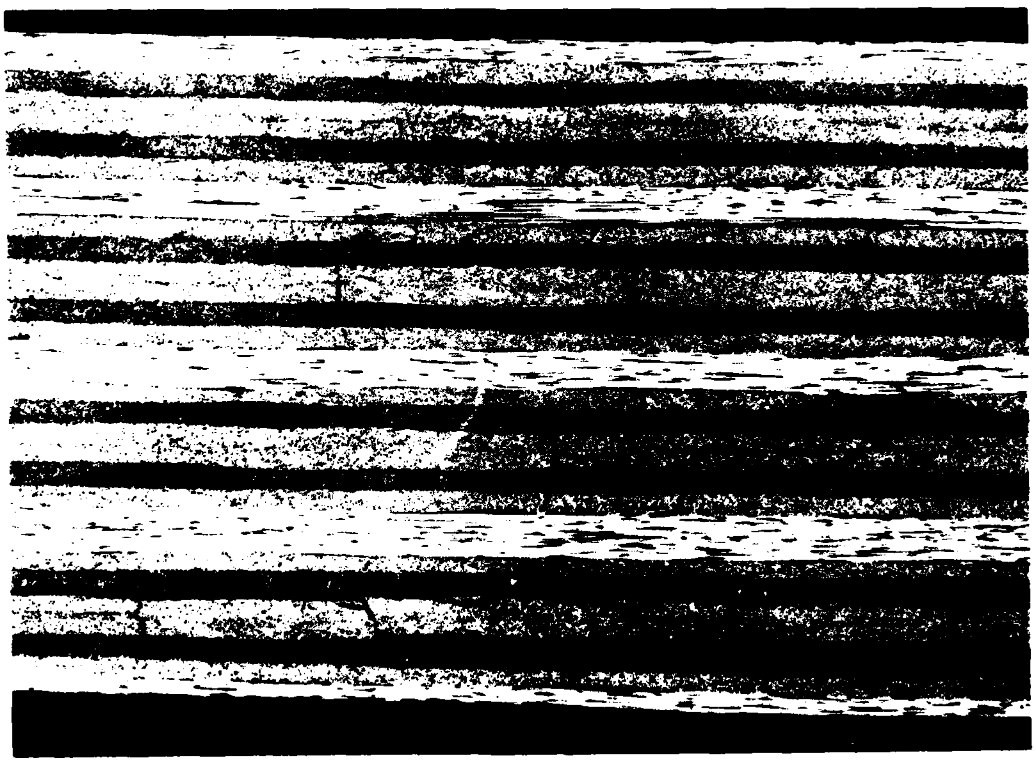
R23-4-2 25X

LOCATION: 0.91 IN. DAMAGE LENGTH: 0.859

LOCATION: 1.01 IN. DAMAGE LENGTH: 0.677



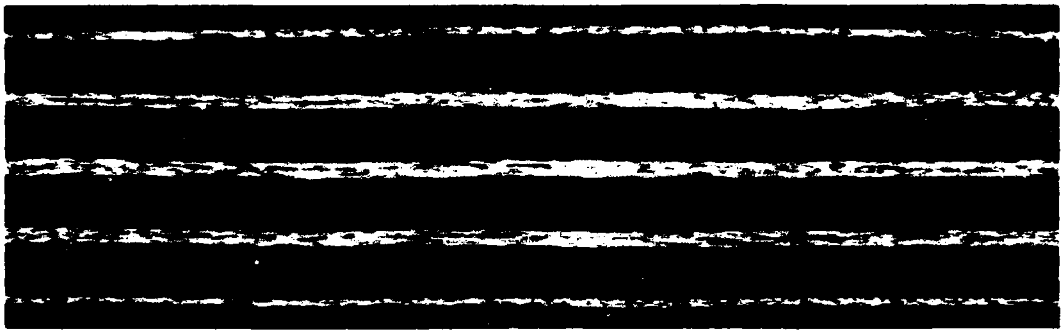
R23-5-1 10X



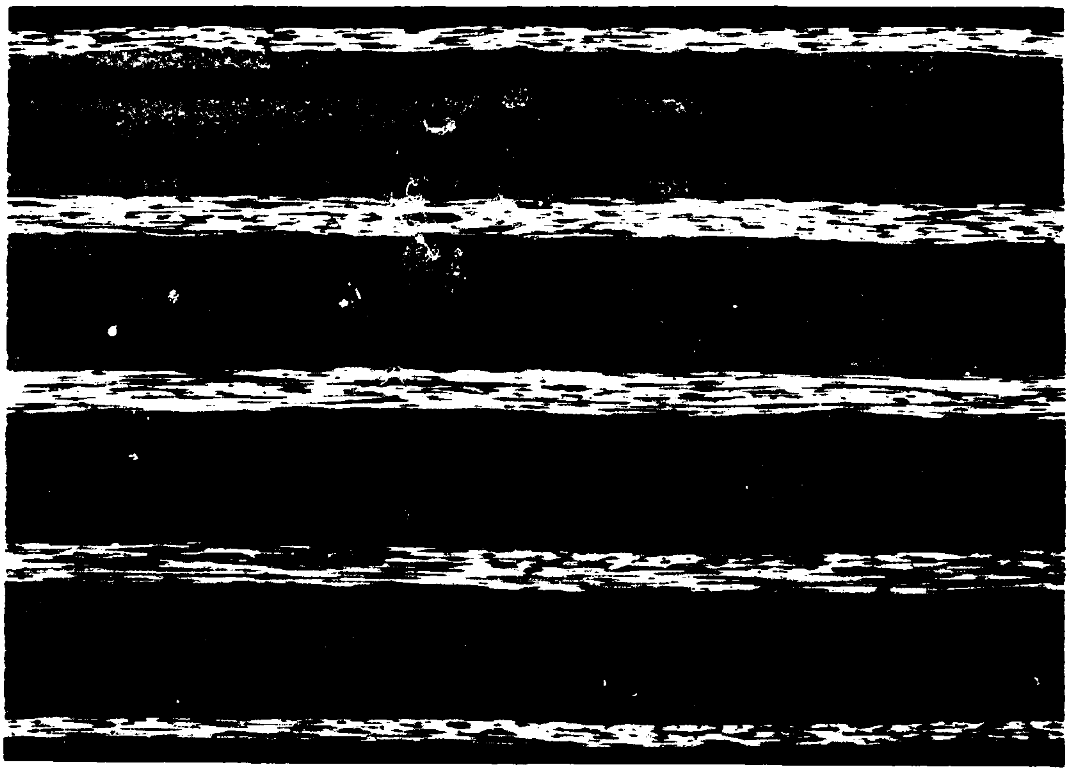
R23-5-2 25X

B-SCAN AT 1.04 IN.

G122



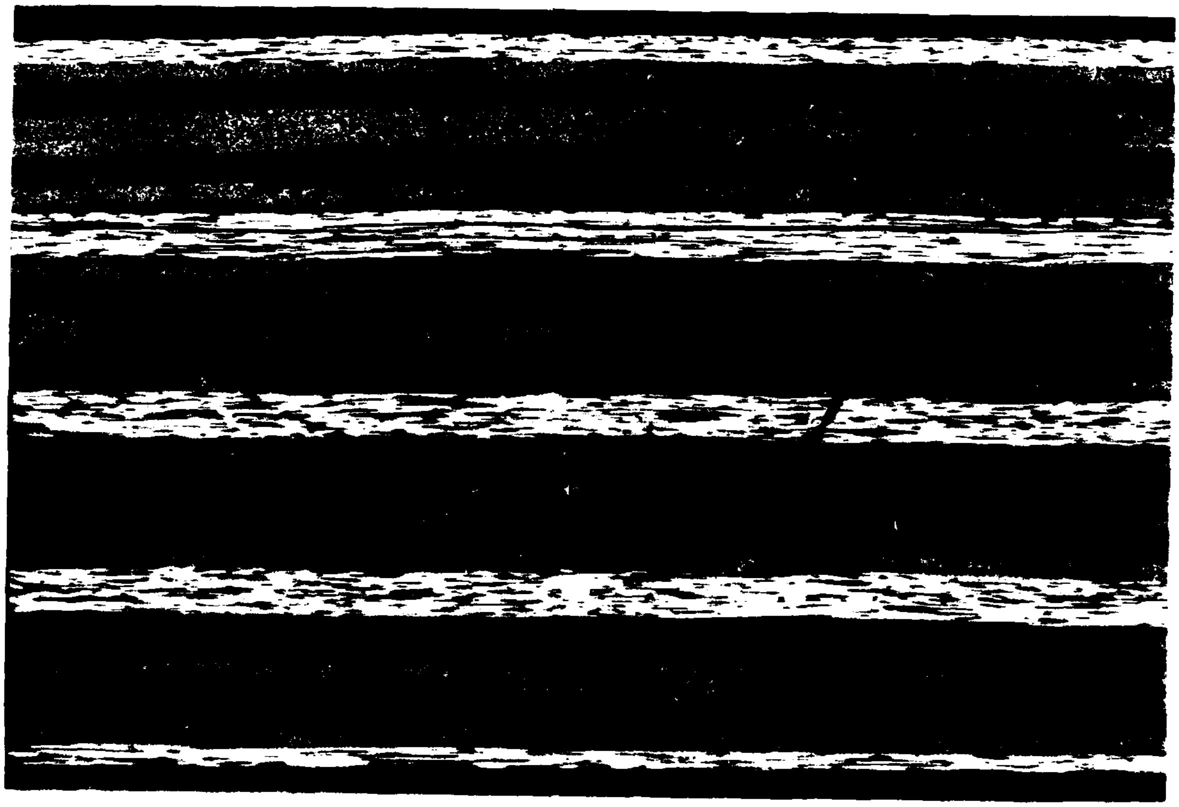
R23-6-1 10X



R23-6-2 25X

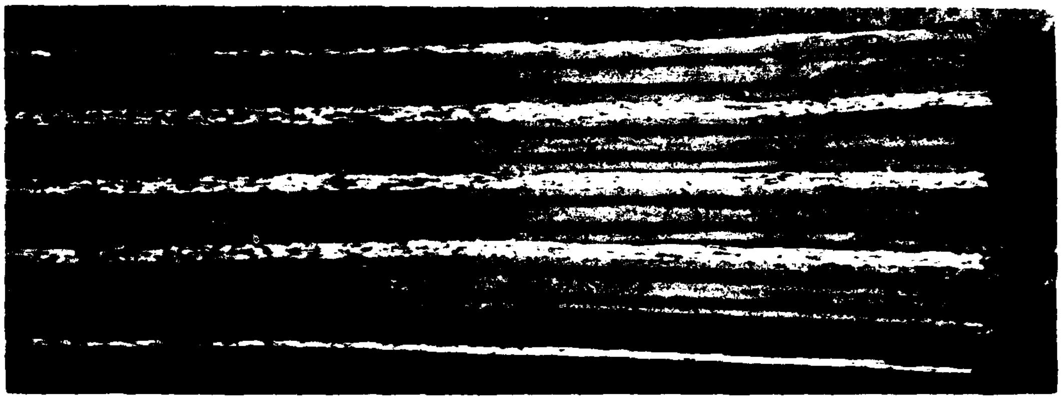
LOCATION: 1.11 IN. DAMAGE LENGTH: 0.709

P23-7-1 10X

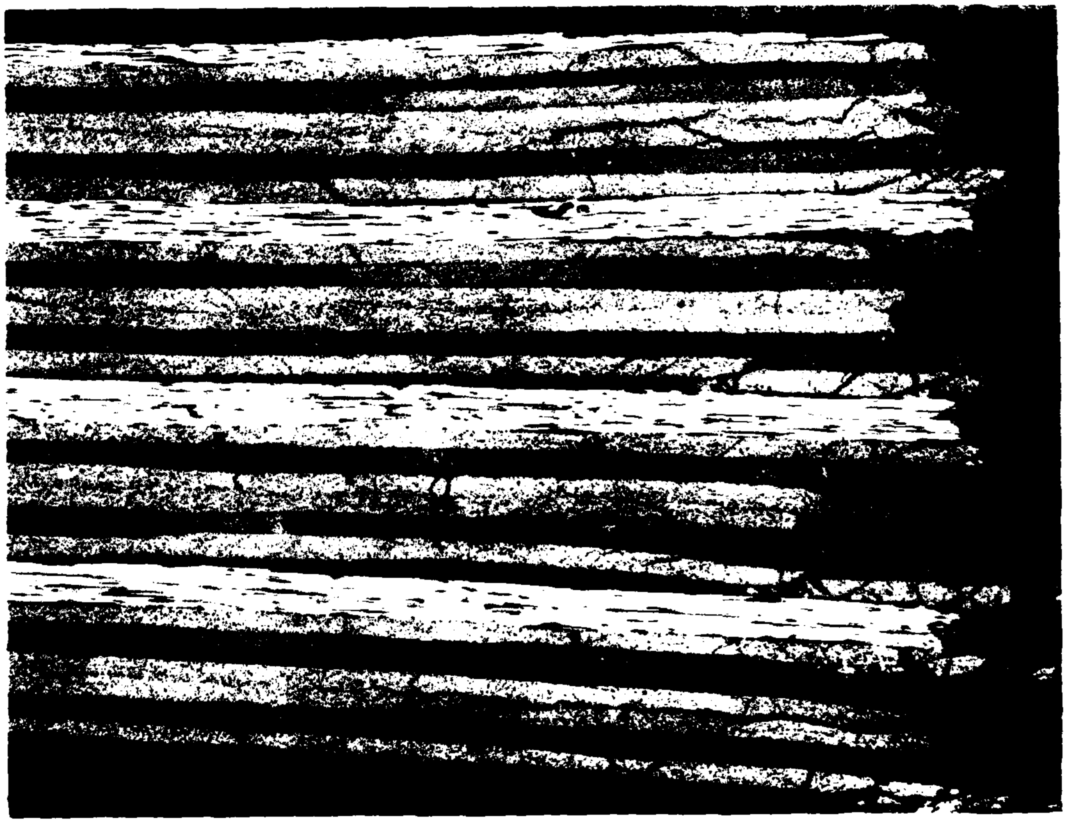


P23-7-2 25X

LOCATION: 1.21 IN. DAMAGE LENGTH: 0.734

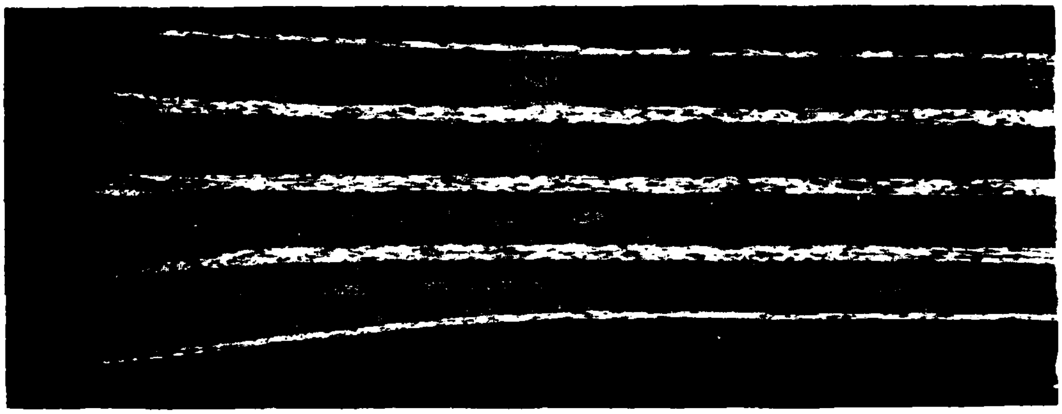


R23-8-1A 10X

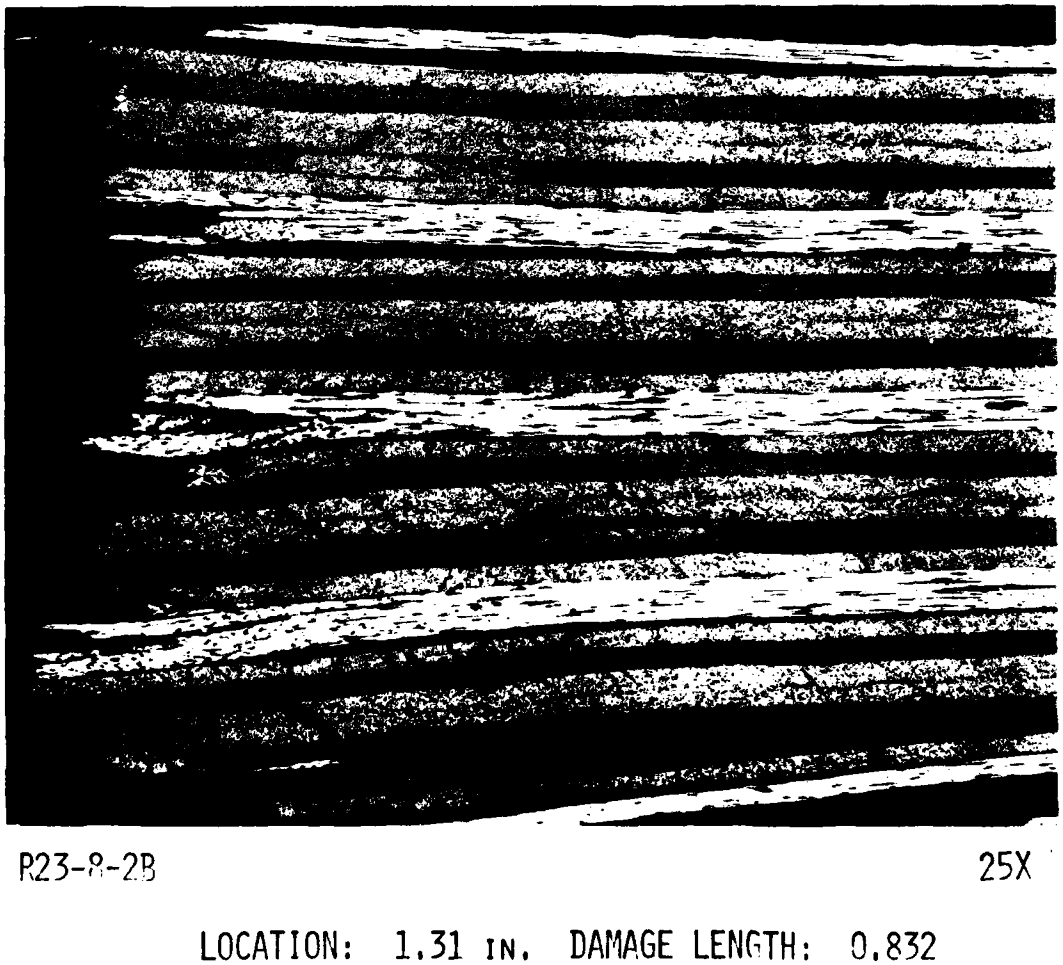


R23-8-2A 25X

LOCATION: 1.31 IN. DAMAGE LENGTH: 0.832

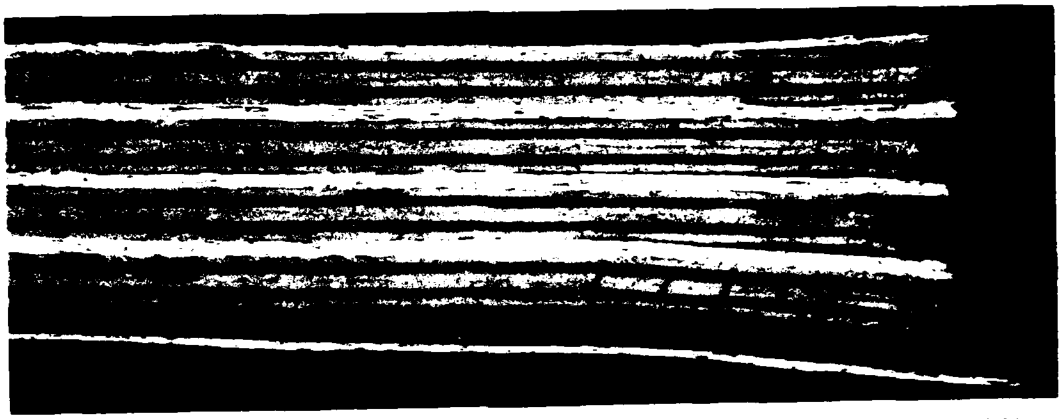


R23-8-1B 10X

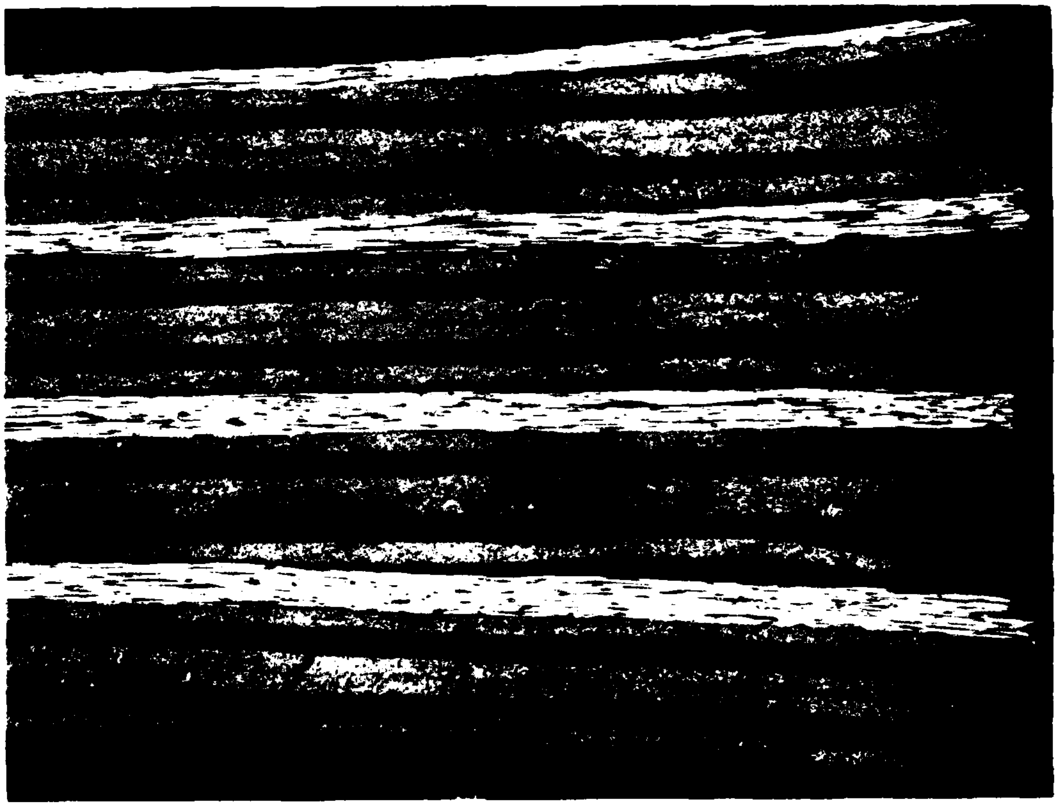


R23-8-2B 25X

LOCATION: 1.31 IN. DAMAGE LENGTH: 0.832

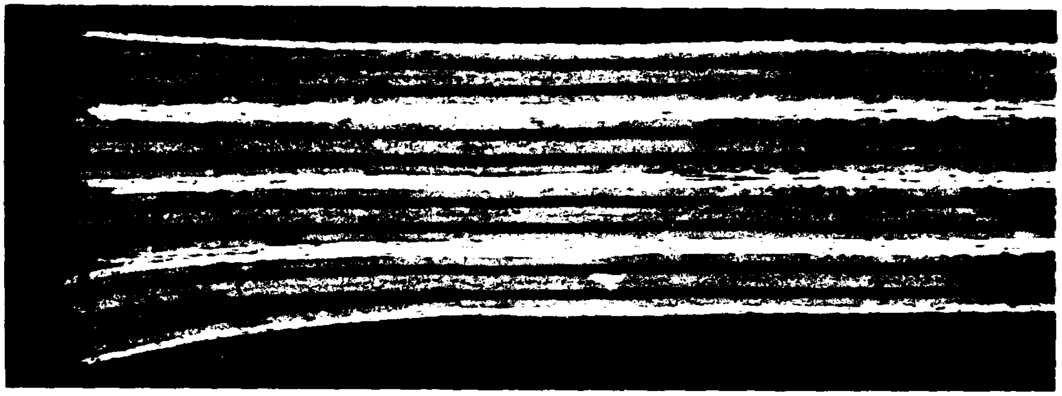


R23-9-1A 10X

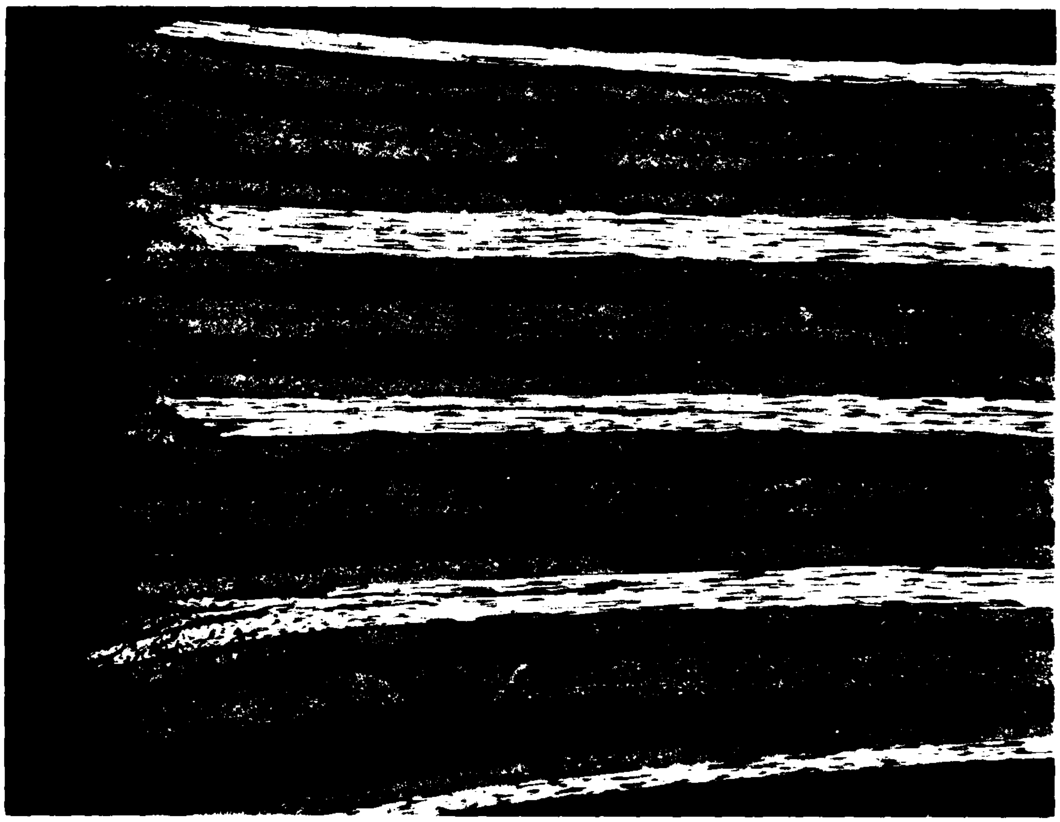


R23-9-2A 25X

LOCATION: 1.41 IN. DAMAGE LENGTH: 0.907



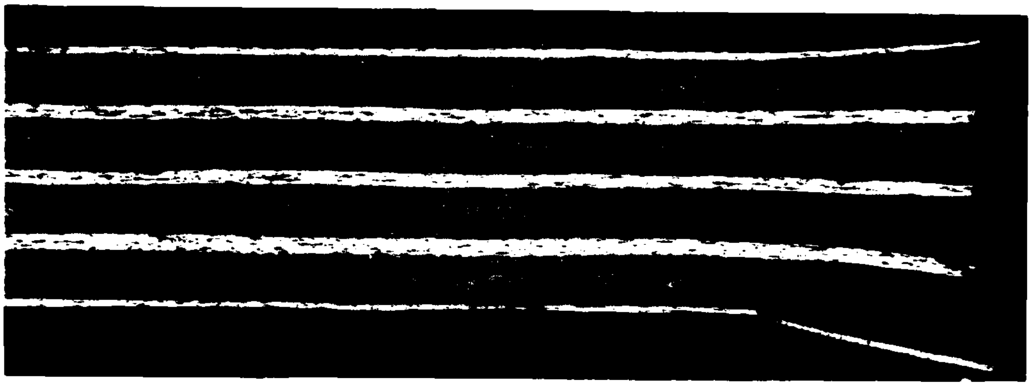
R23-9-1B 10X



R23-9-2B 25X

LOCATION: 1.41 IN. DAMAGE LENGTH: 0.907

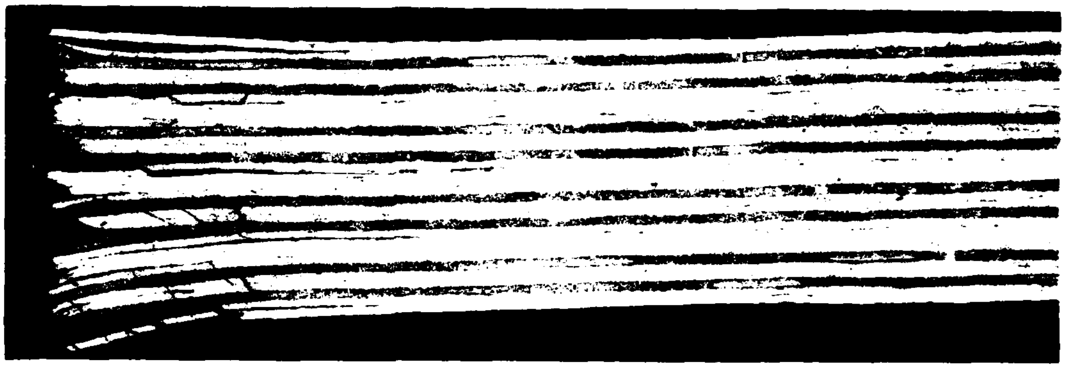
LOCATION: 1.51 IN. DAMAGE LENGTH: 0.926



R23-10-1A 10X

R23-10-2A 25X

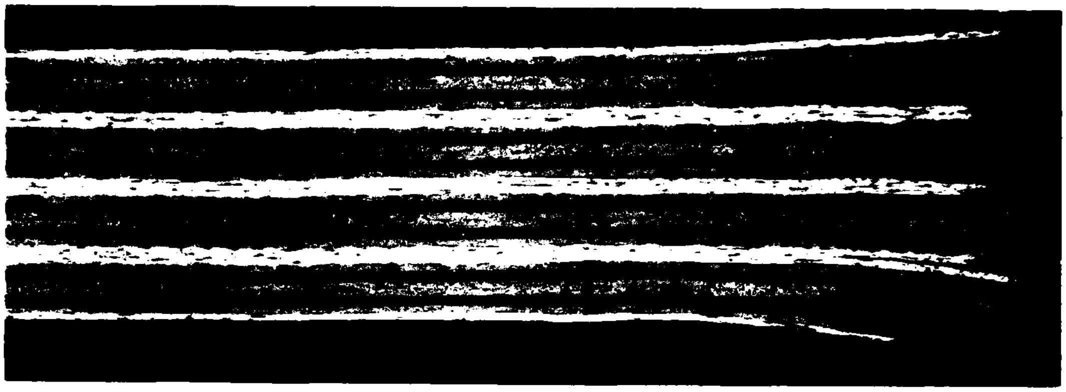
B-SCAN AT CENTER



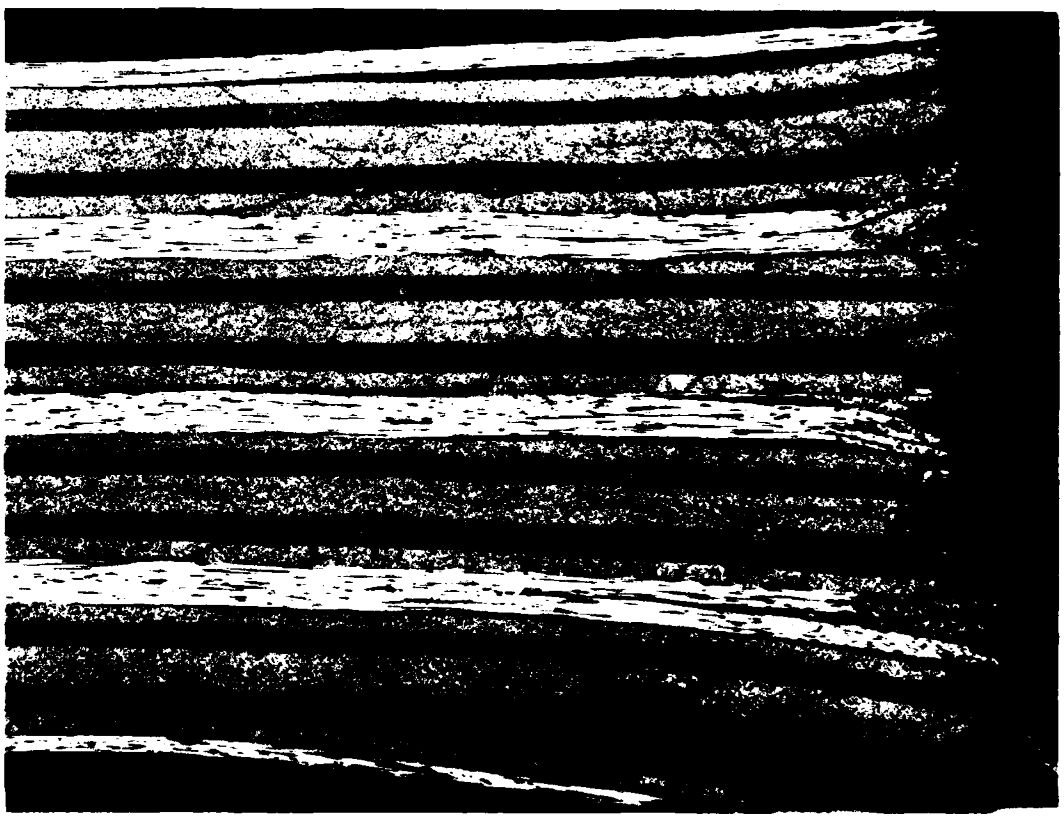
R23-10-1B 10X

R23-10-2B 25X

LOCATION: 1.51 IN. DAMAGE LENGTH: 0.926



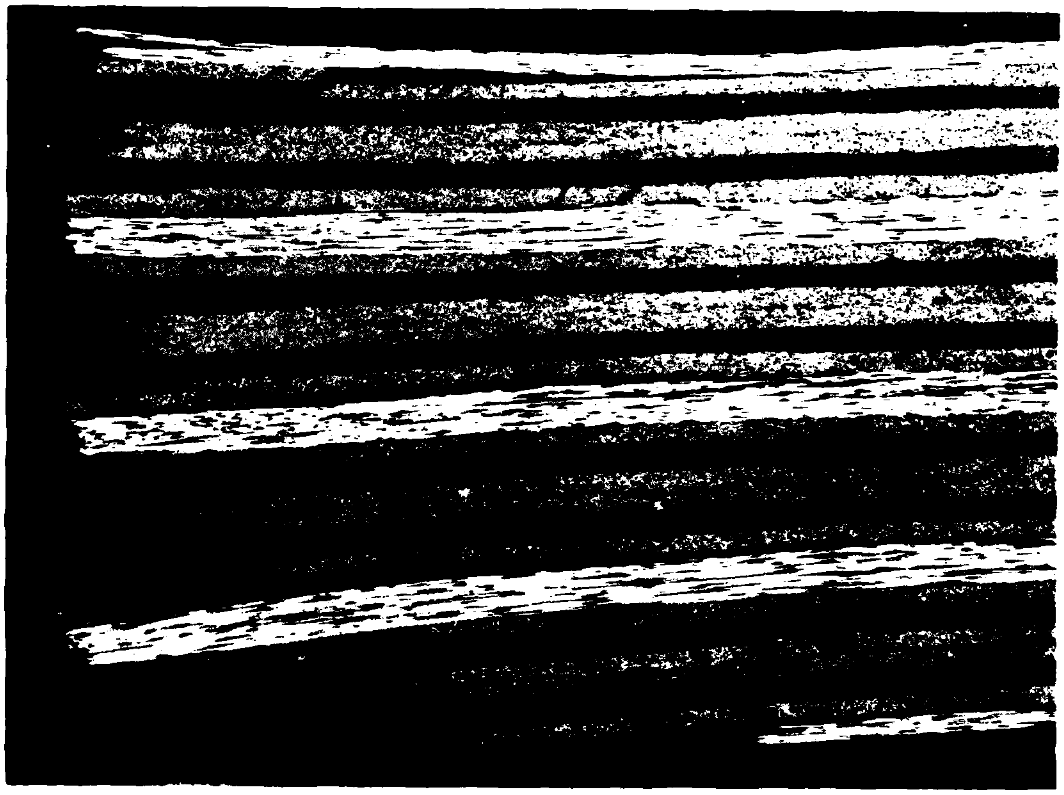
R23-11-1A 10X



R23-11-2A 25X

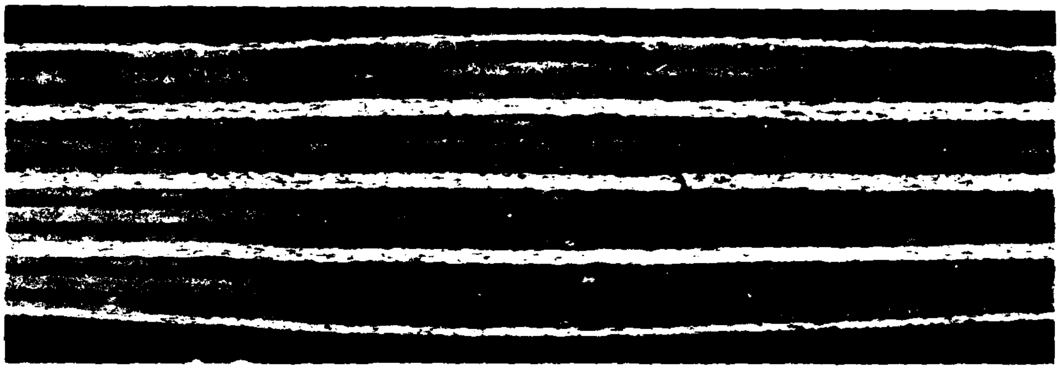
LOCATION: 1.61 IN. DAMAGE LENGTH: 0.882

R23-11-1B 10X

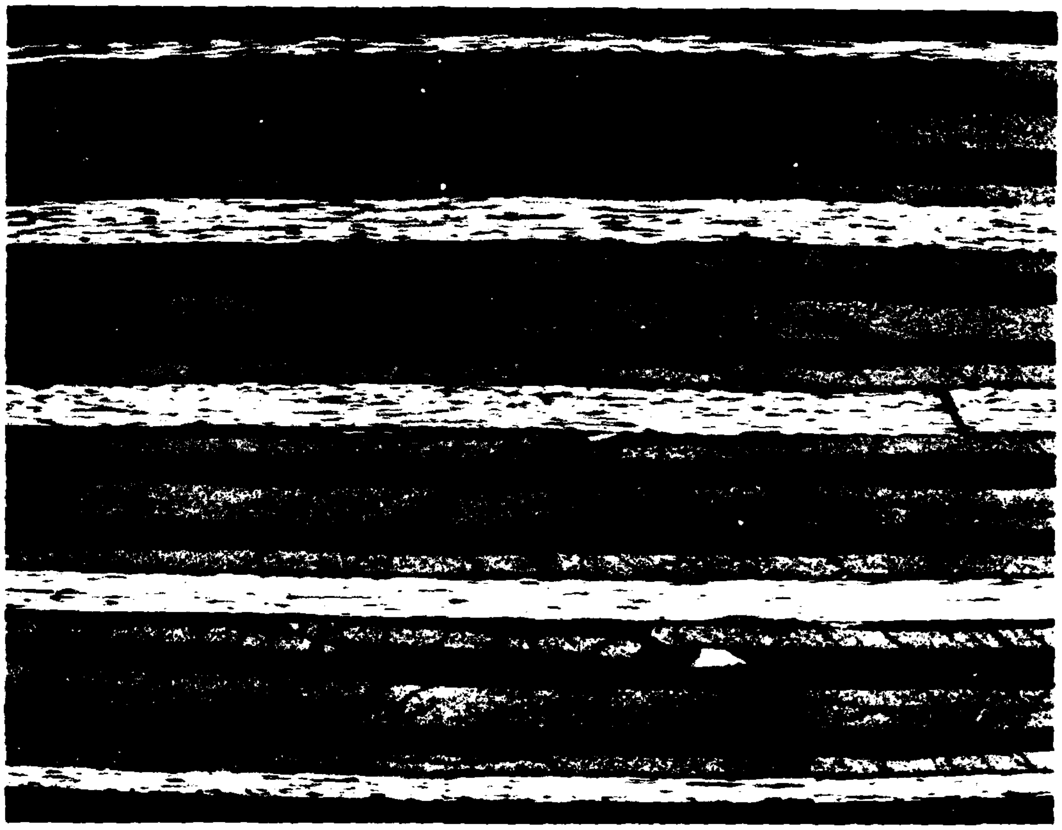


R23-11-2B 25X

LOCATION: 1.61 IN. DAMAGE LENGTH: 0.882

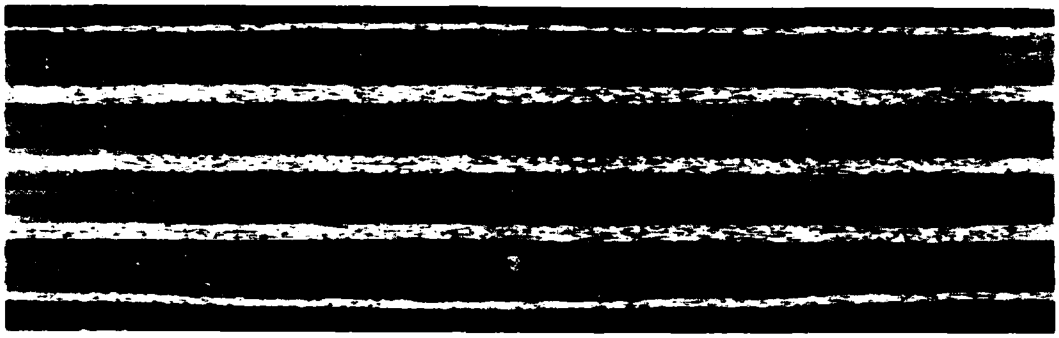


R23-12-1 10X

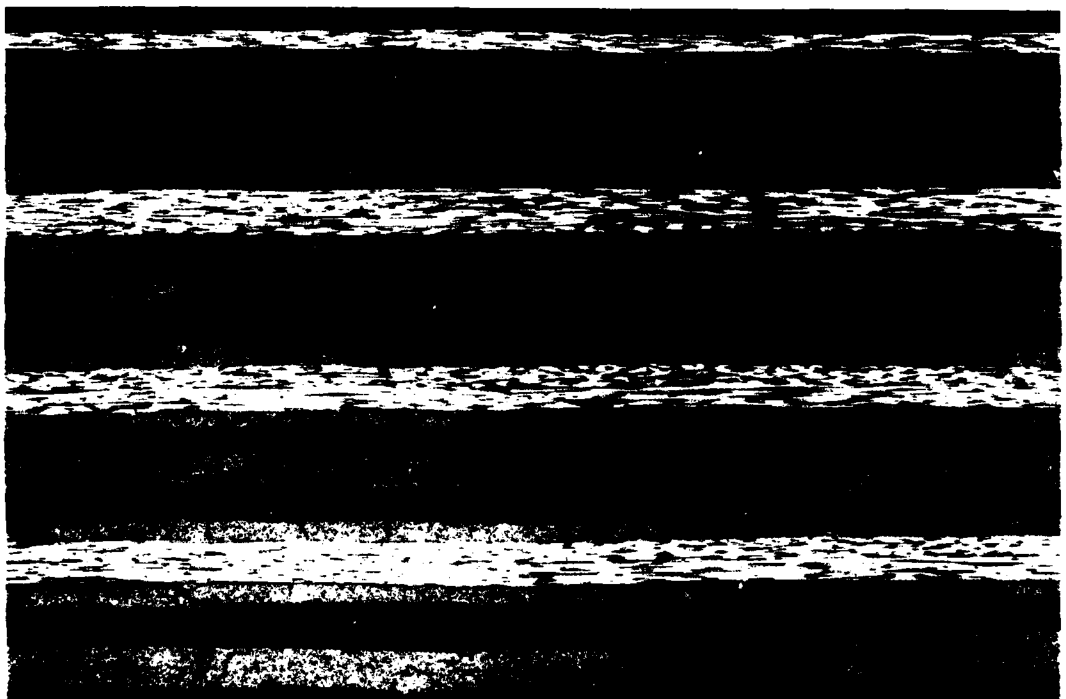


R23-12-2 25X

LOCATION: 1.71 IN. DAMAGE LENGTH: 0.763

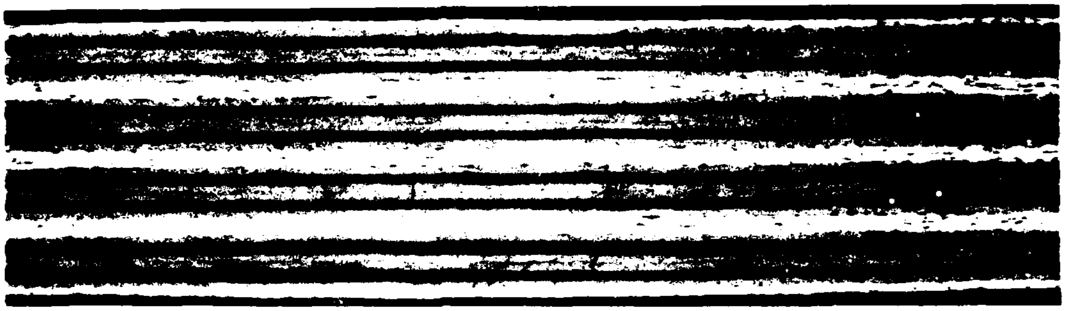


R23-13-1 10X

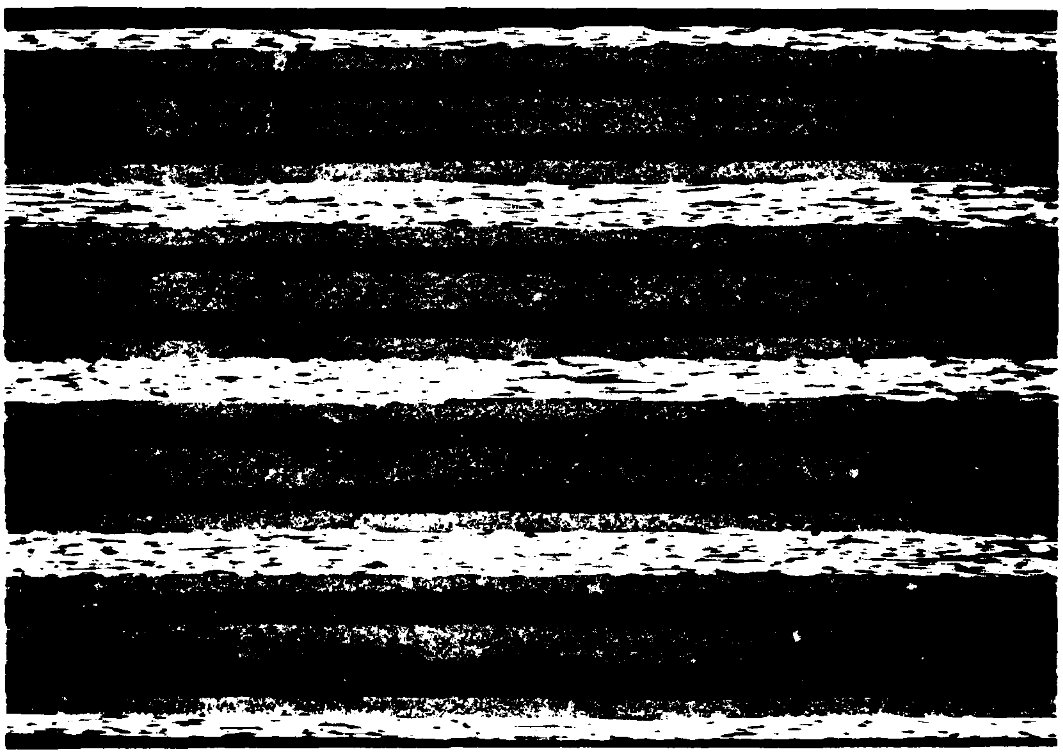


R23-13-2 25X

LOCATION: 1.81 IN. DAMAGE LENGTH: 0.702



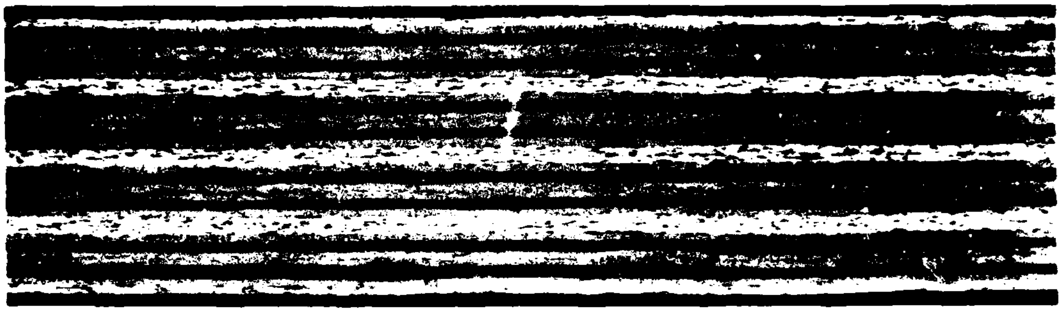
R23-14-1 10X



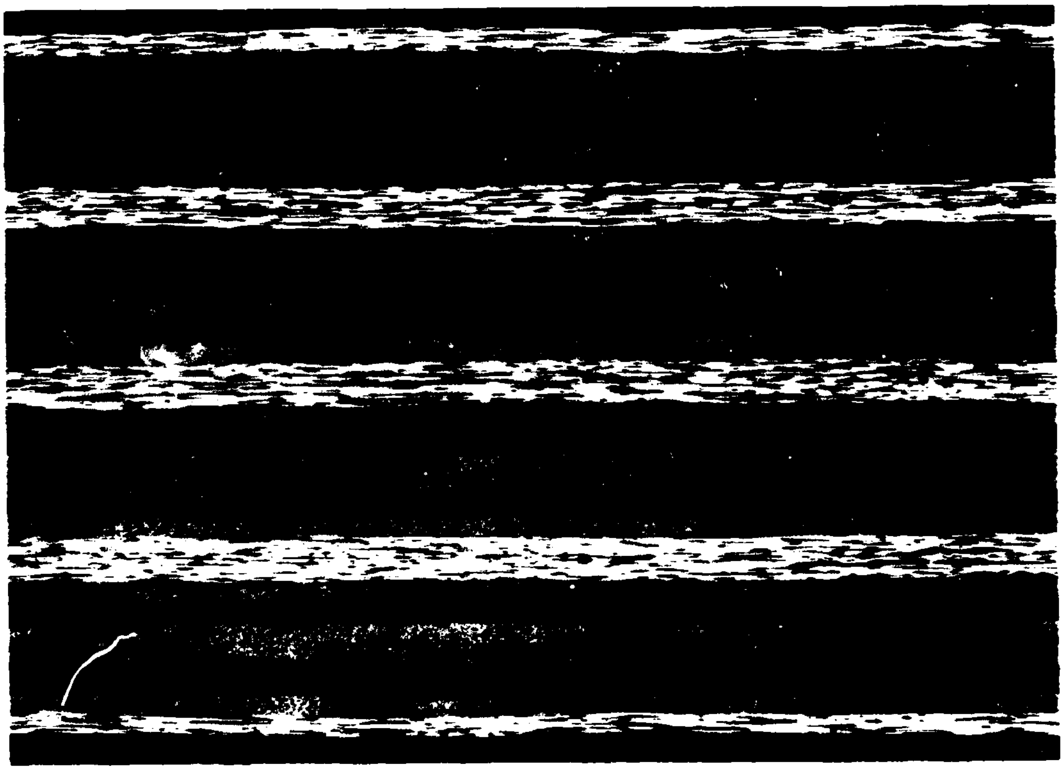
R23-14-2 25X

LOCATION: 1.91 IN. DAMAGE LENGTH: 0.649

LOCATION 2.01 IN. DAMAGE LENGTH: 0.635



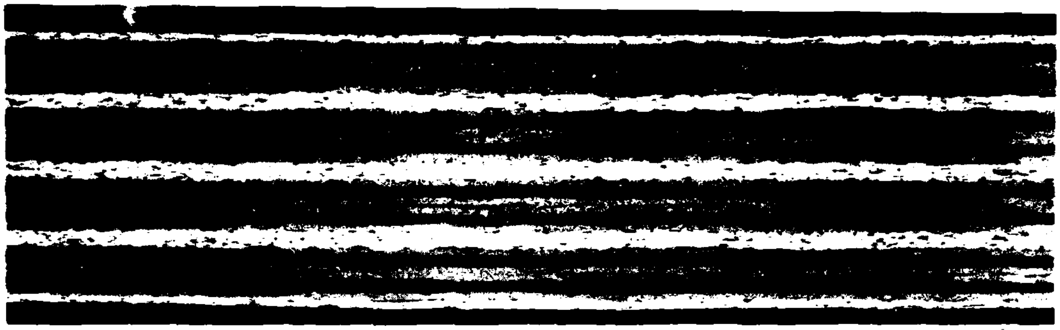
R23-15-1 10X



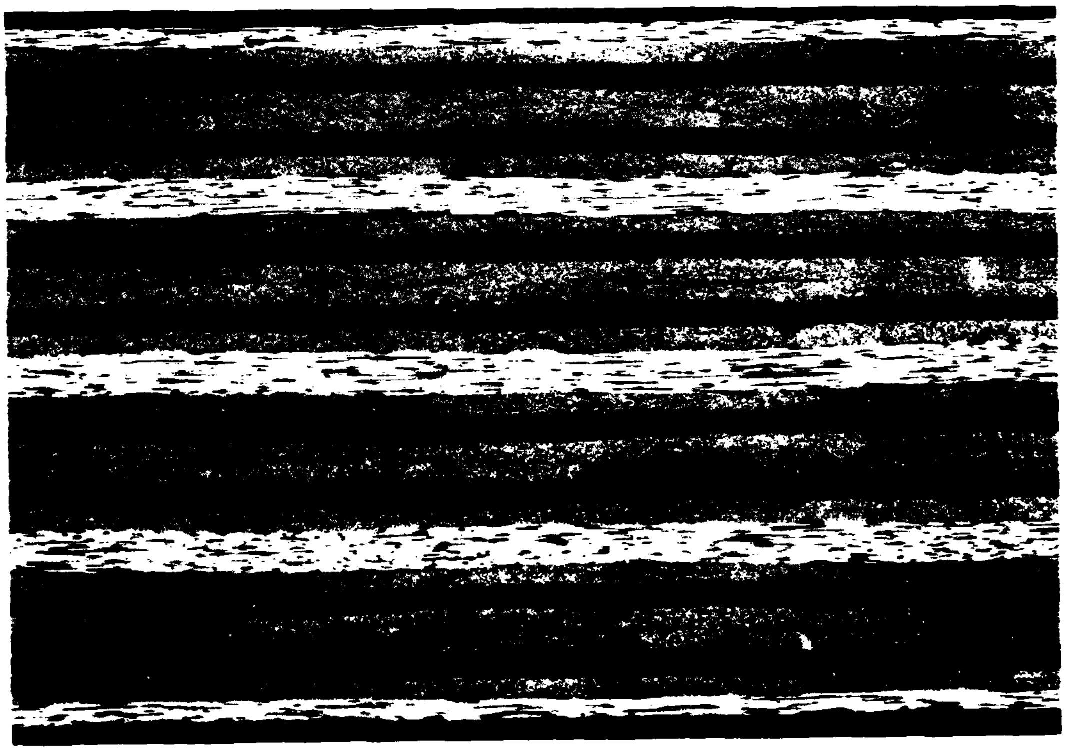
R23-15-2 25X

B-SCAN AT 2.02 IN.

G136

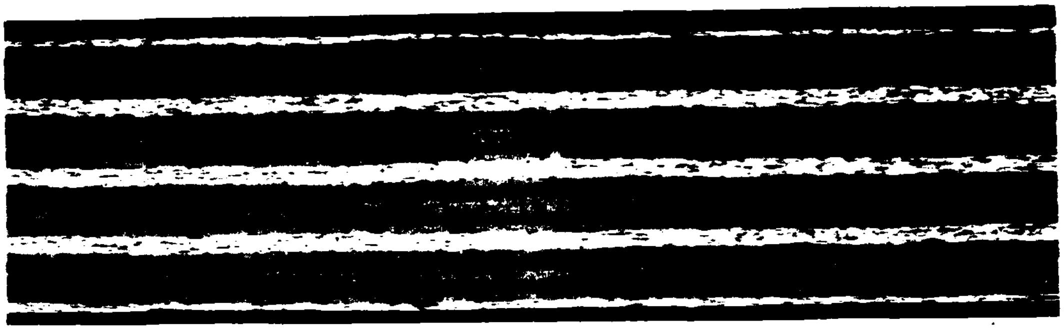


R23-16-1 10X

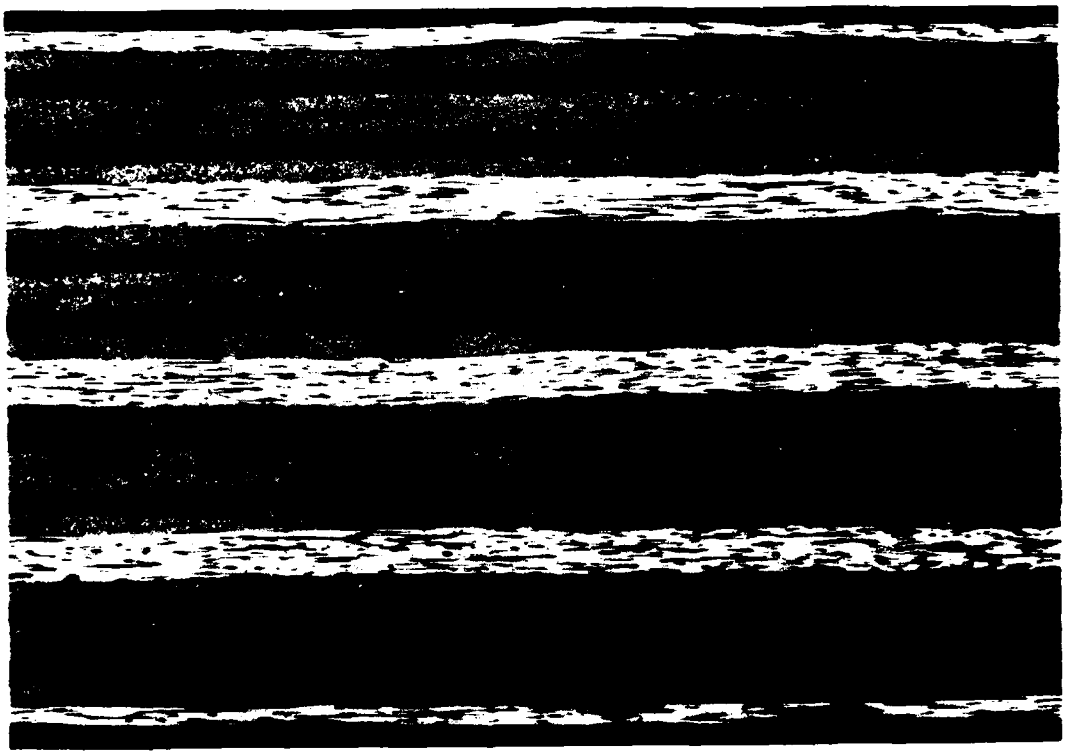


R23-16-2 25X

LOCATION: 2.11 IN. DAMAGE LENGTH: 0.571

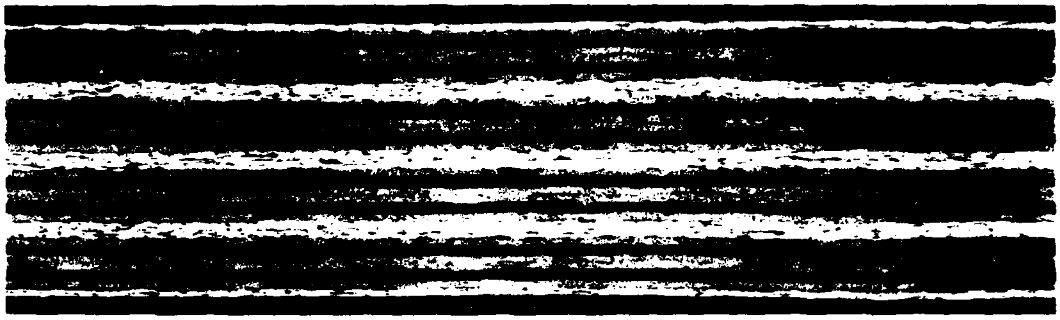


R23-17-1 10X

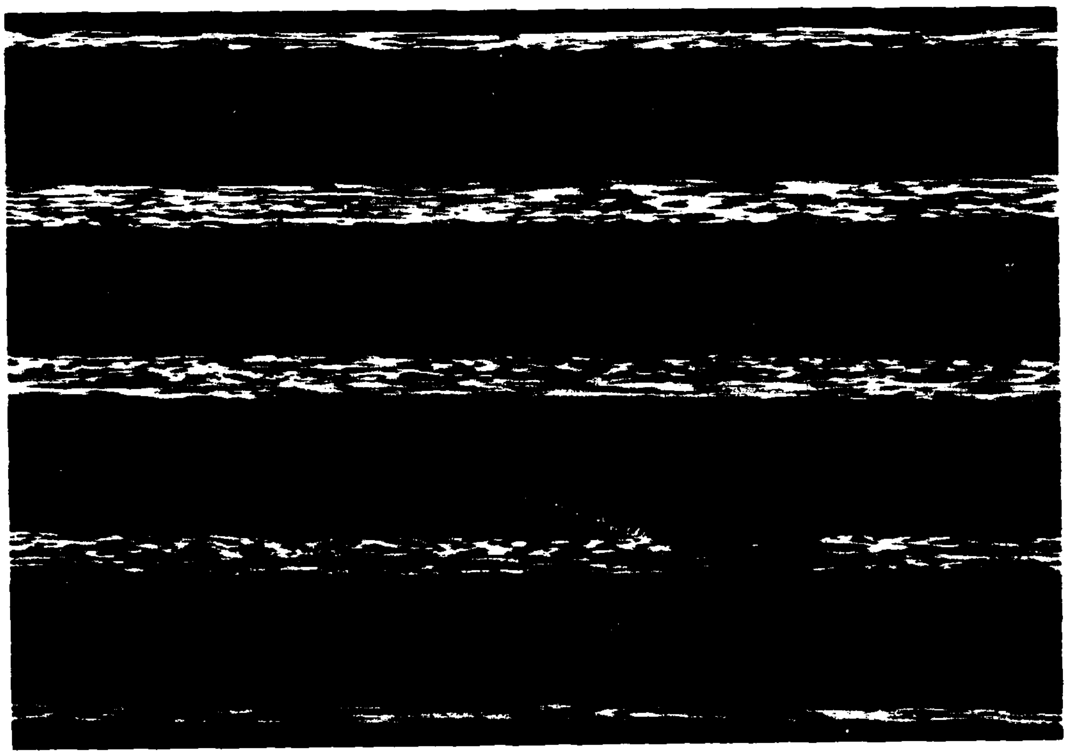


R23-17-2 25X

LOCATION: 2.21 IN. DAMAGE LENGTH: 0.396



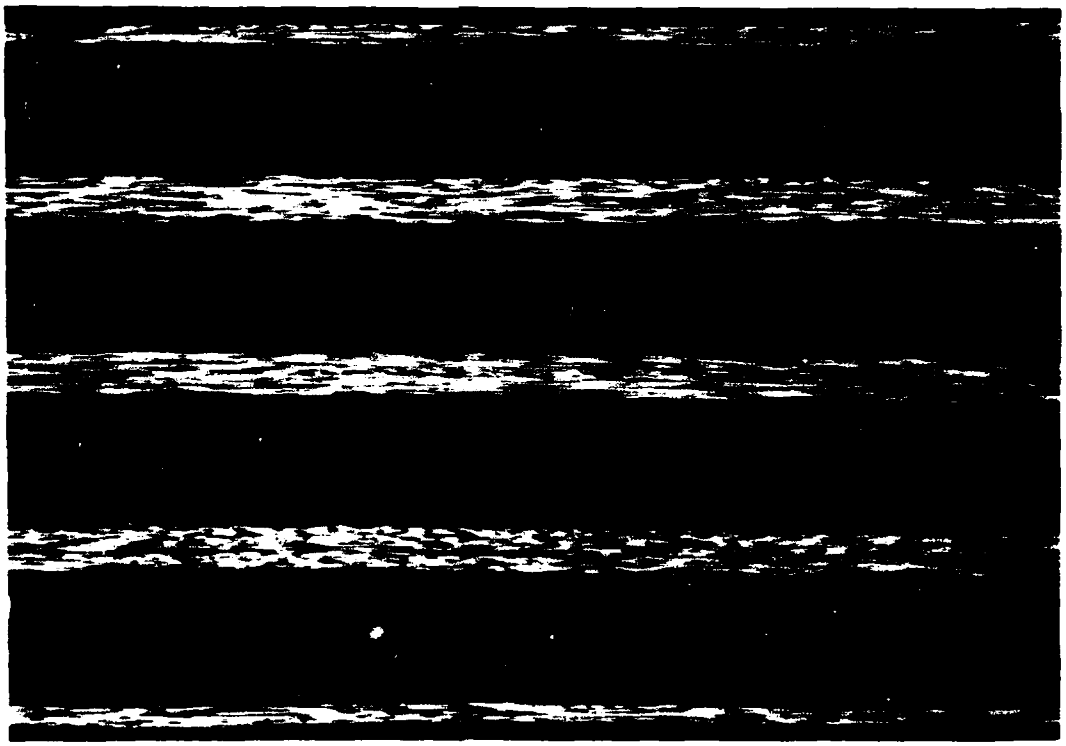
R23-18-1 10X



R23-18-2 25X

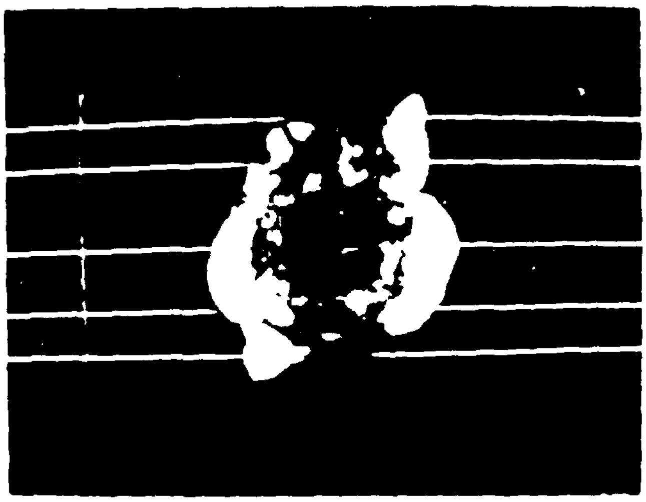
LOCATION: 2.31 IN. DAMAGE LENGTH: 0.241

R23-19-1 10X

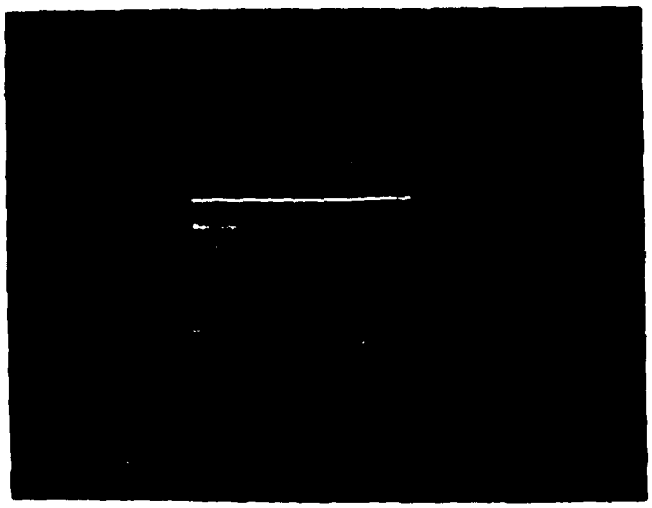


R23-19-2 25X

LOCATION: 2.41 IN. DAMAGE LENGTH: NO DAMAGE

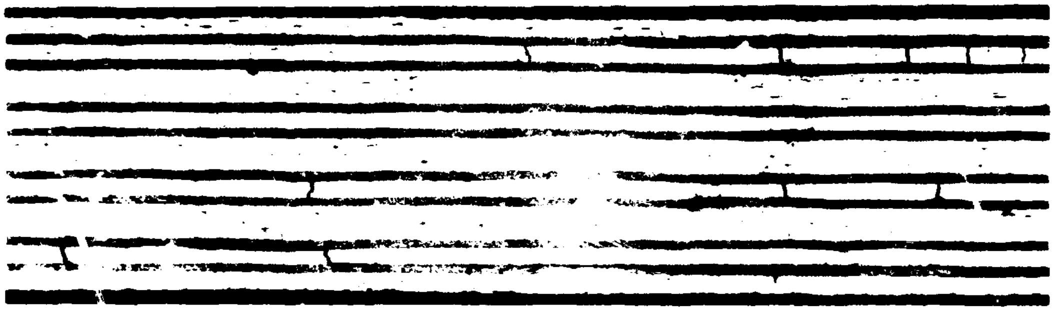


C-SCAN

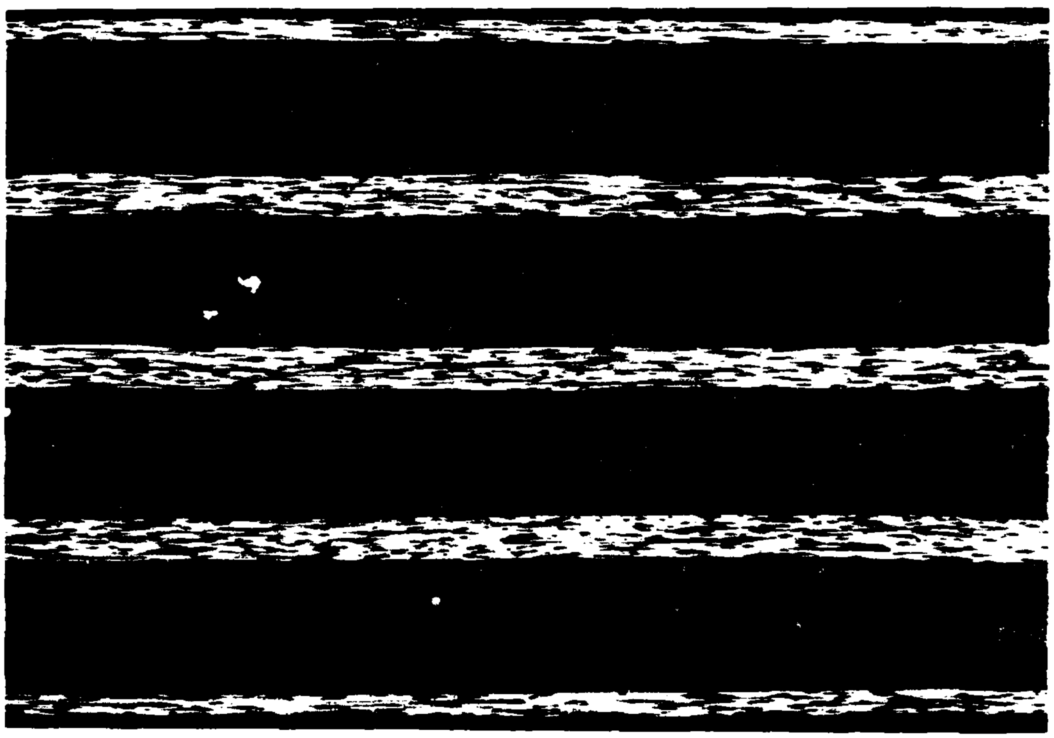


CUMULATIVE B-SCAN

32-PLY SPEC: NB-19 N_4 = 20,000 CYCLES

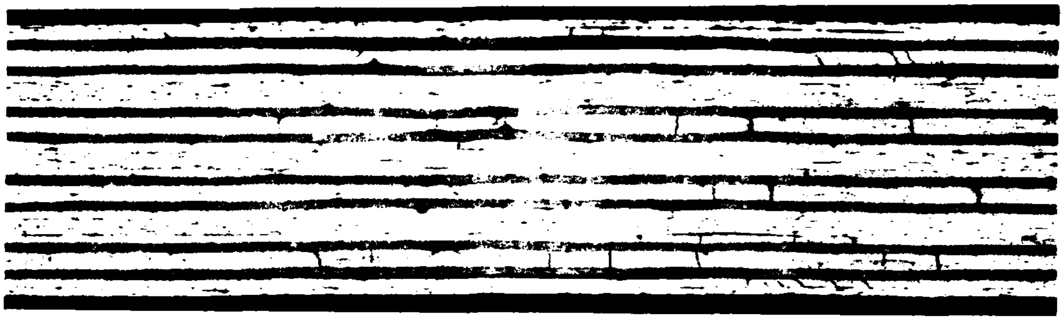


10X

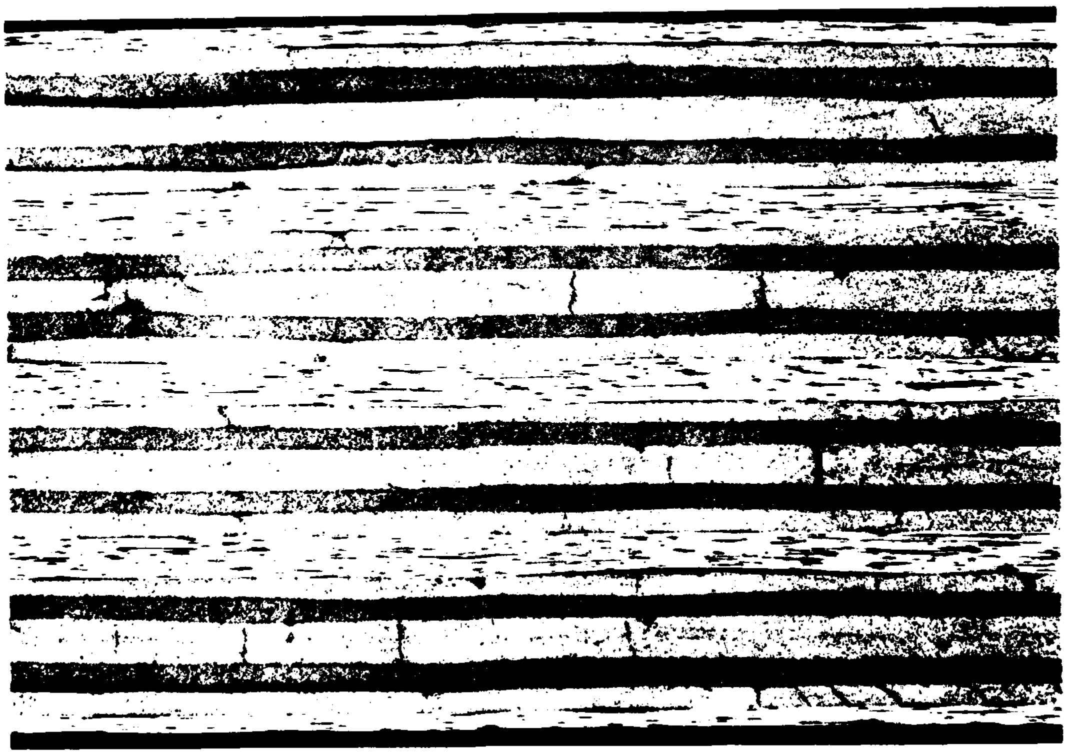


N19-1-2 25X

LOCATION: 0.98 IN. DAMAGE LENGTH: 0.750



N19-2-1 10X

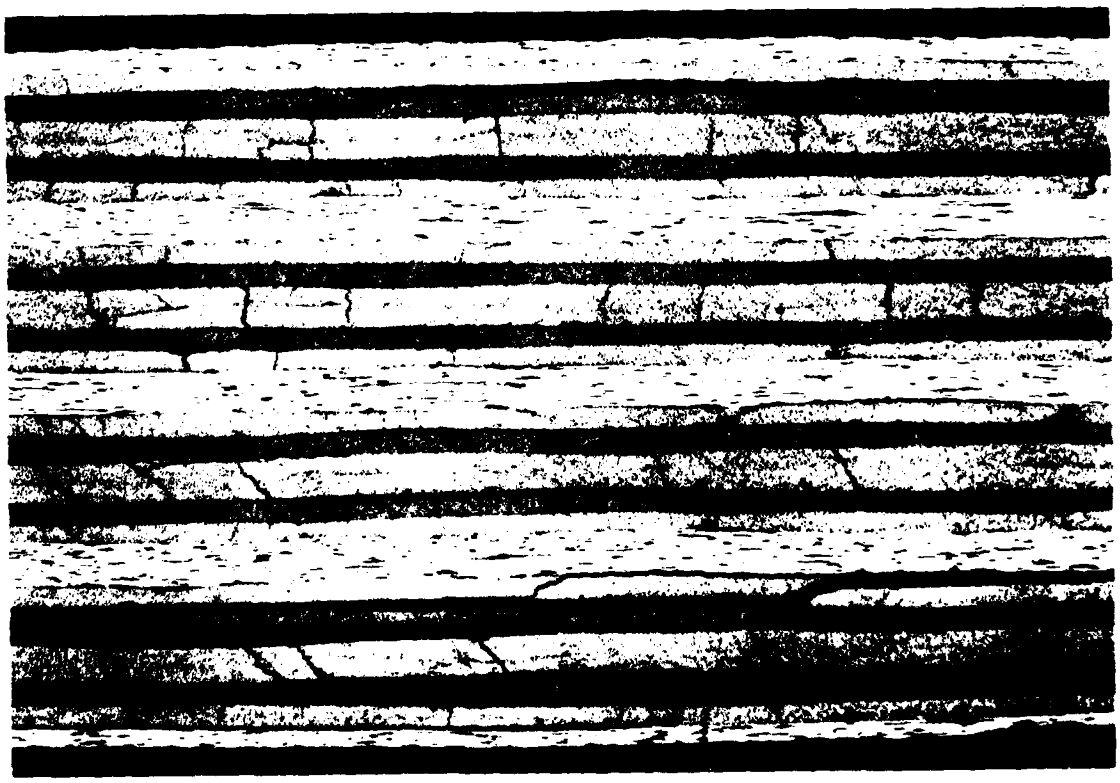


N19-2-2 25X

LOCATION: 1.08 IN. DAMAGE LENGTH: 0.717

LOCATION: 1.18 IN. DAMAGE LENGTH: 0.764

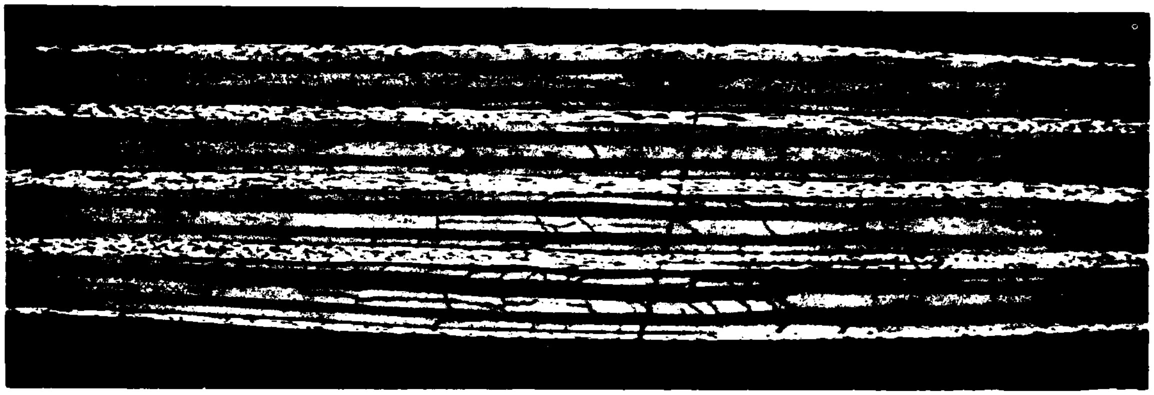
N19-3-1 10X



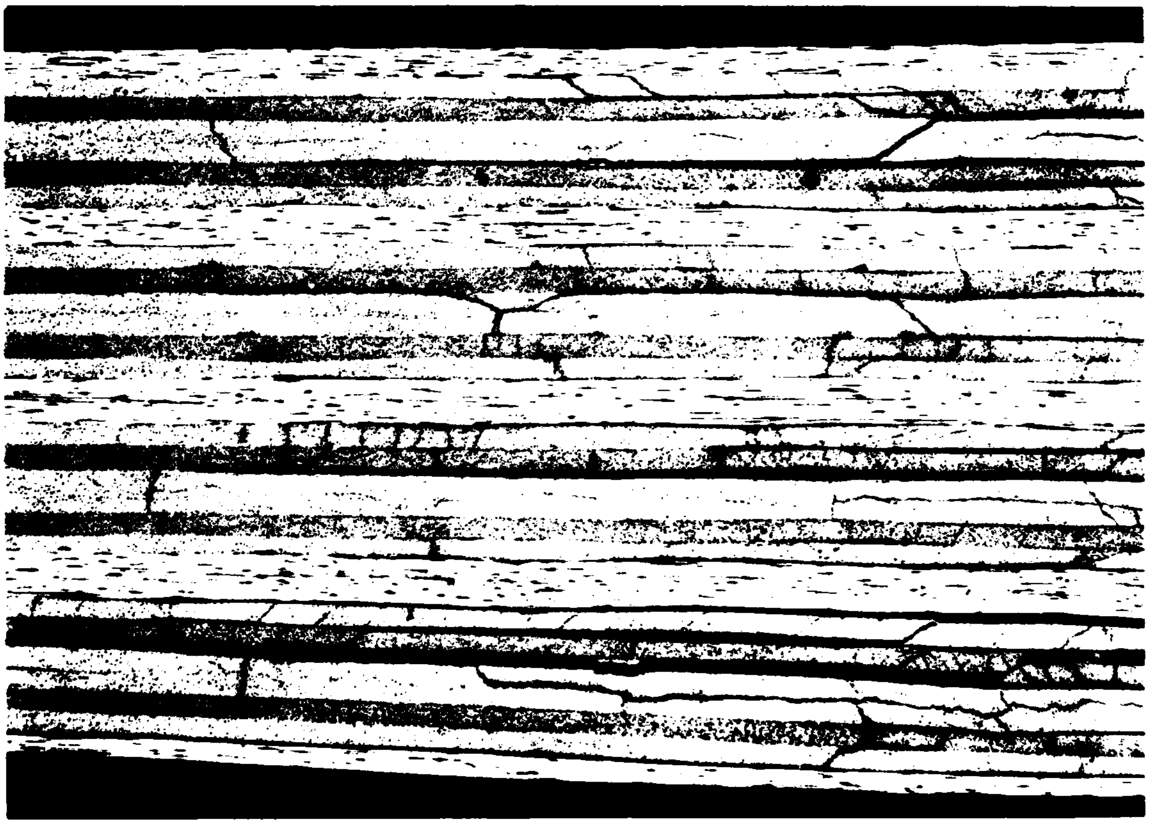
N19-3-2 25X

B-SCAN AT 1.17 IN.

G144

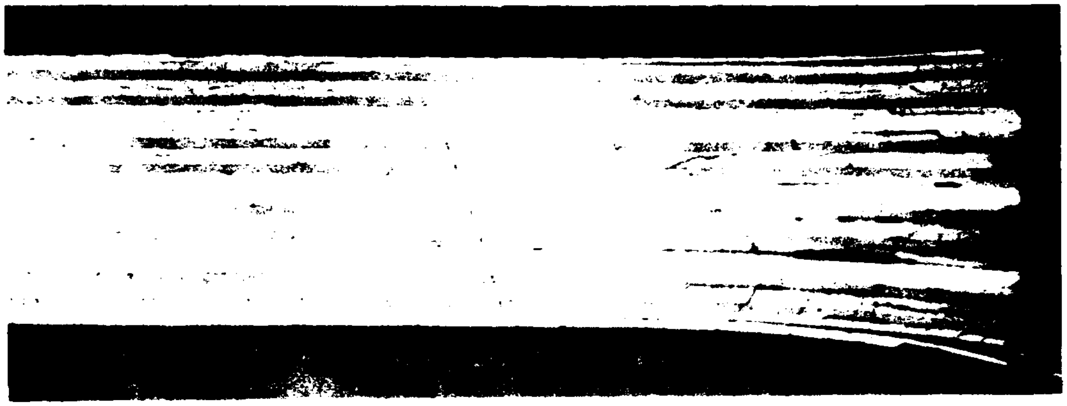


N19-4-1 10X



N19-4-2 25X

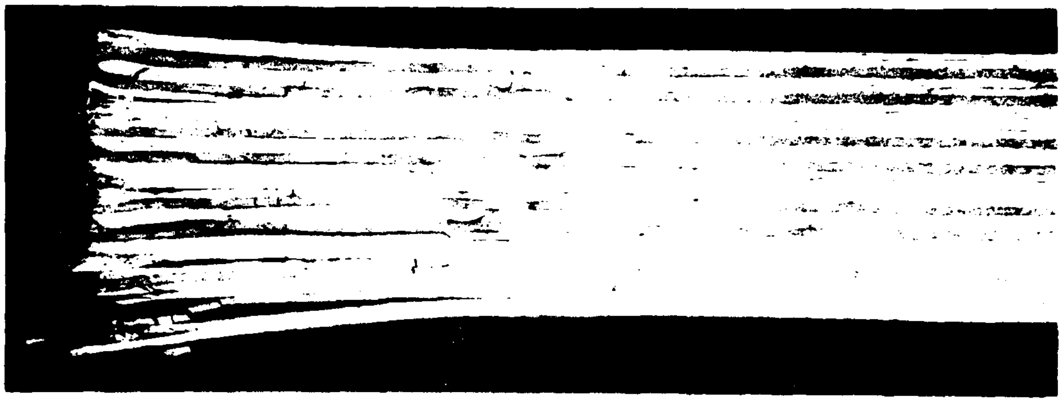
LOCATION: 1.28 IN. DAMAGE LENGTH: 0.73[illegible]



N10-5-1A 10X

N10-5-2A 25X

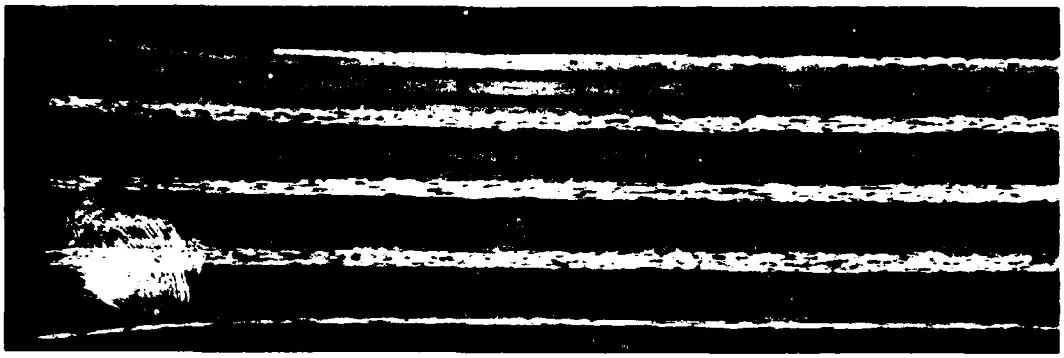
LOCATION: 1.38 IN. DAMAGE LENGTH: 0.835



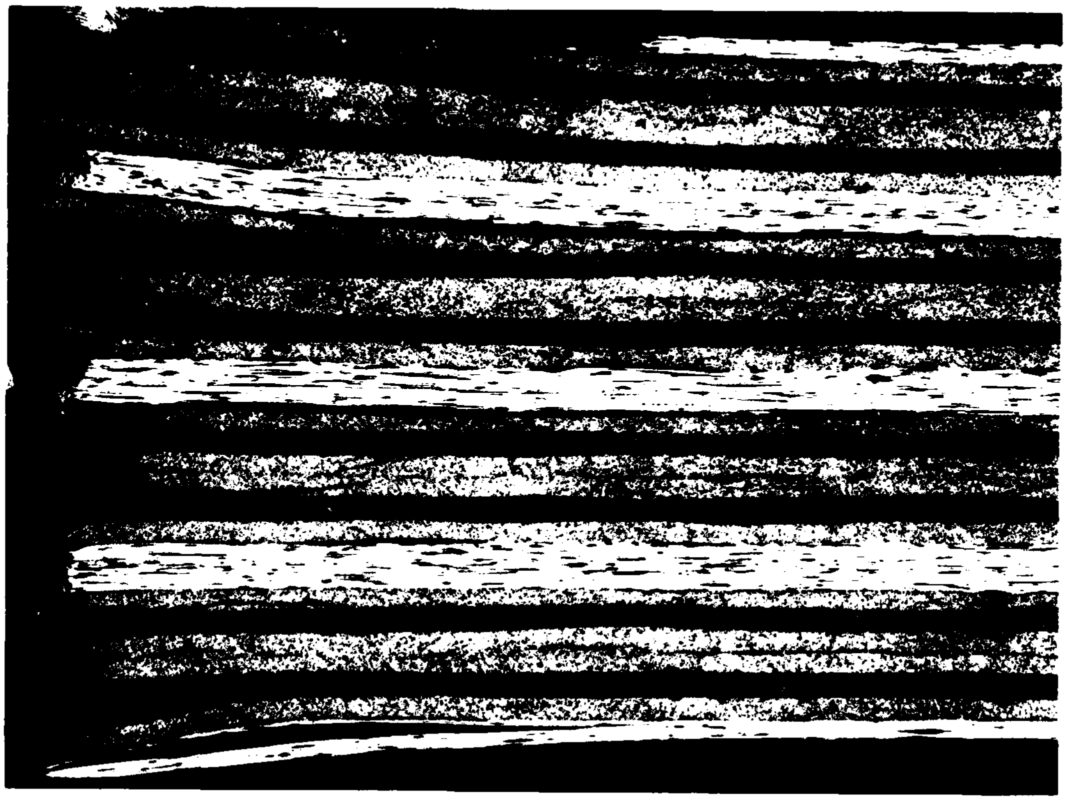
N19-5-1B 10X

N19-5-2B 25X

LOCATION: 1.38 IN. DAMAGE LENGTH: 0.833



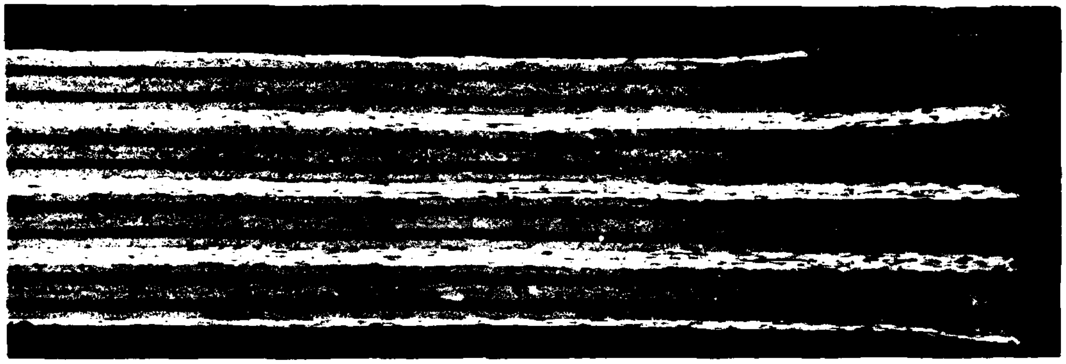
N19-6-1A 10X



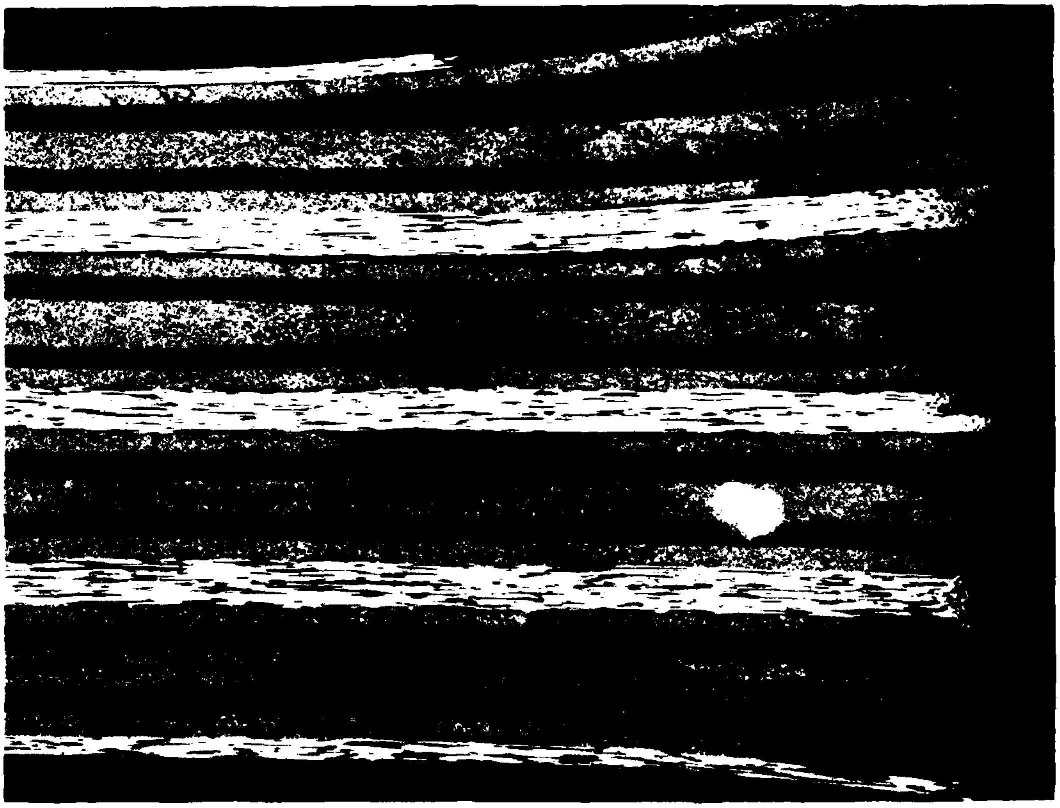
N19-6-2A 25X

B-SCAN AT CENTER

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.918

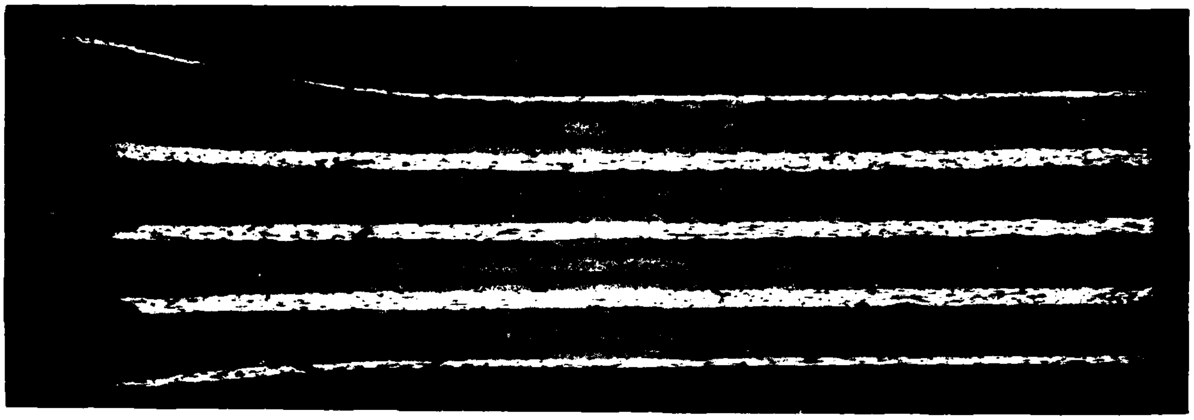


N19-6-1B 10X

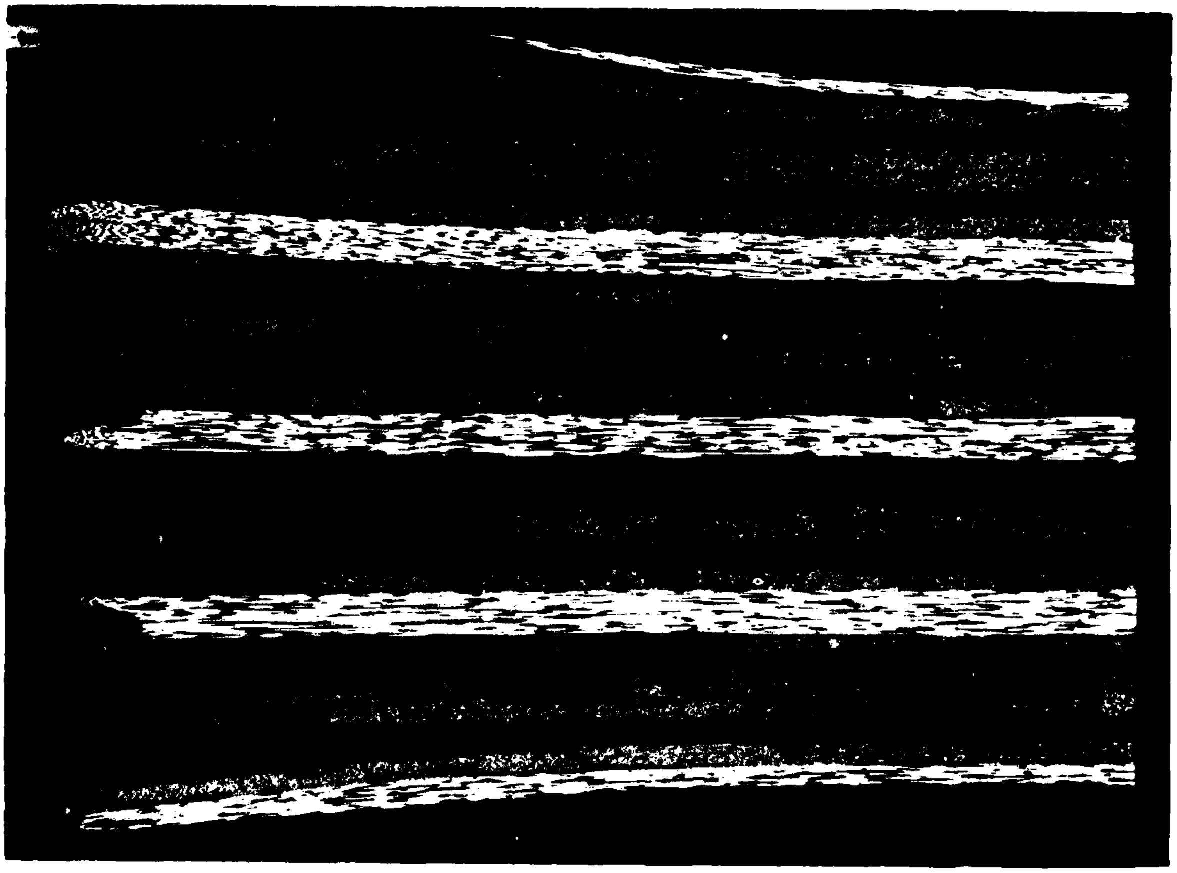


N19-6-2B 25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.918

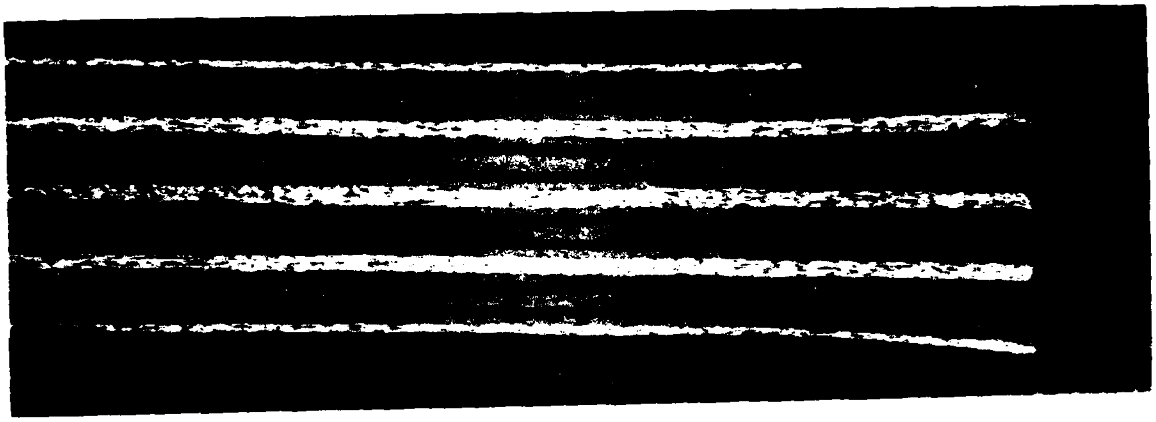


N19-7-1A 10X

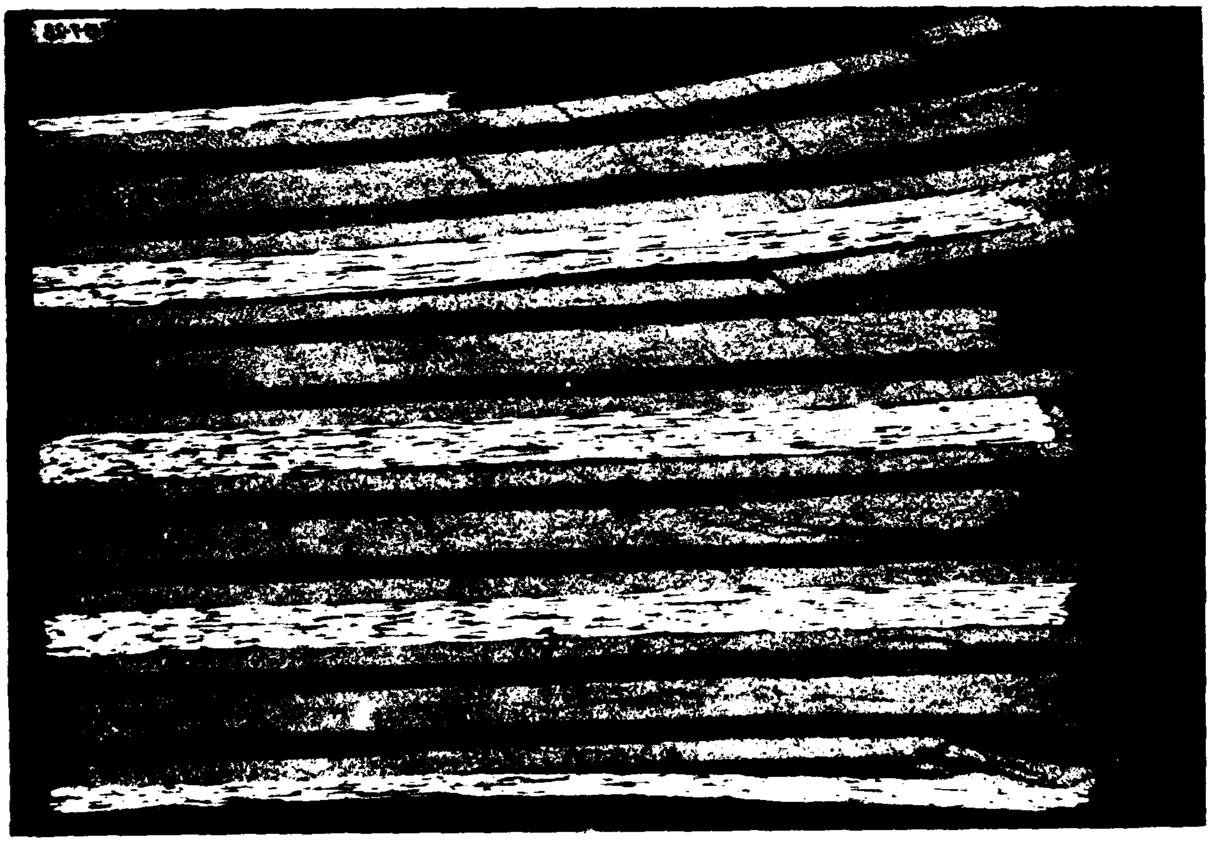


N19-7-2A 25X

LOCATION: 1.58 IN. DAMAGE LENGTH: 0.028

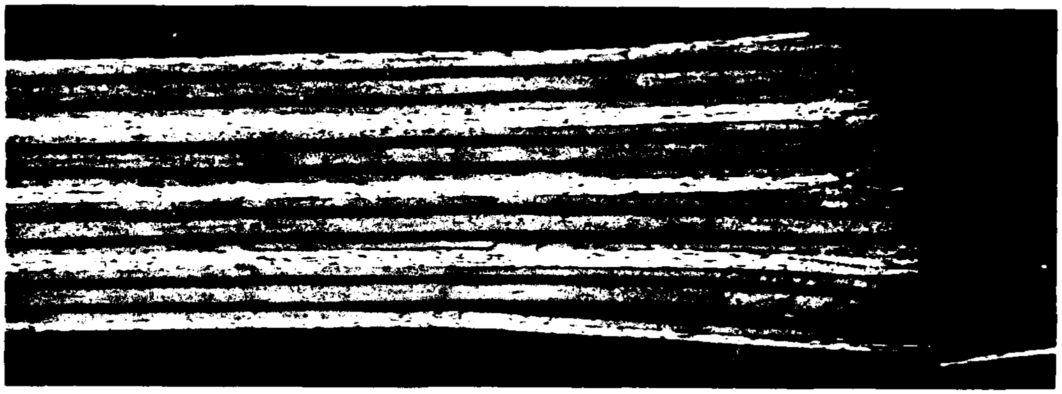


N19-7-1B

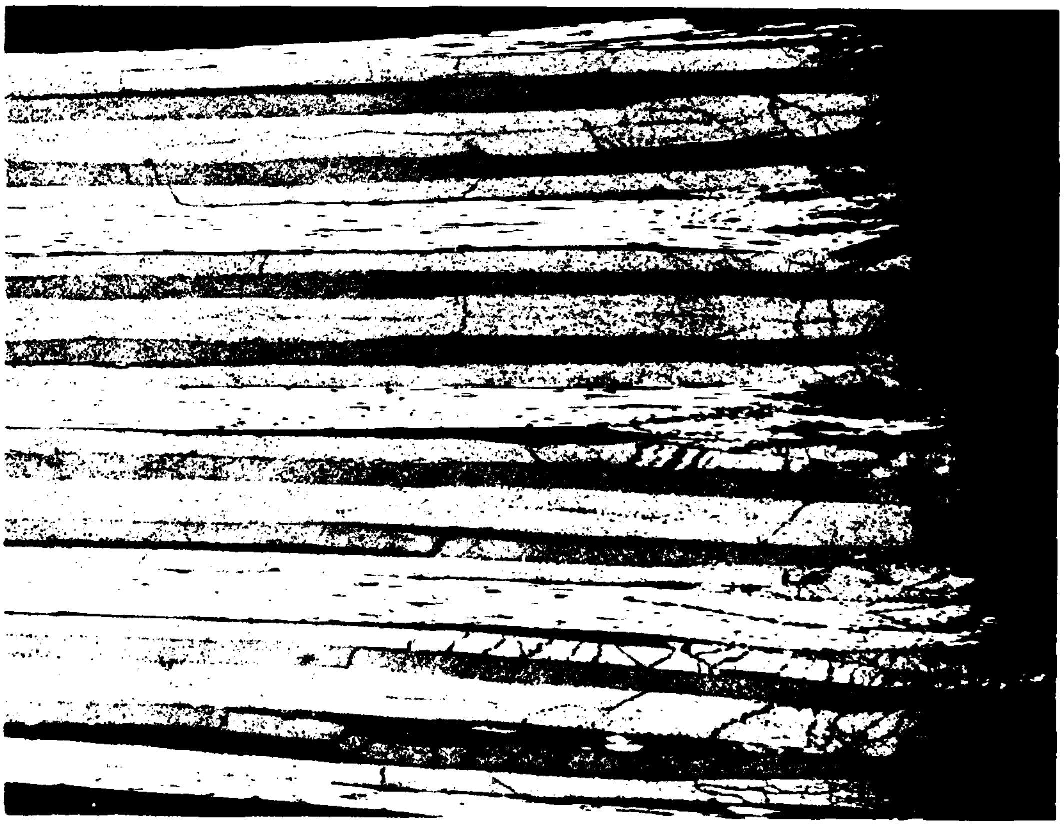


N19-7-2B

LOCATION: 1.58 IN. DAMAGE LENGTH: 0.028

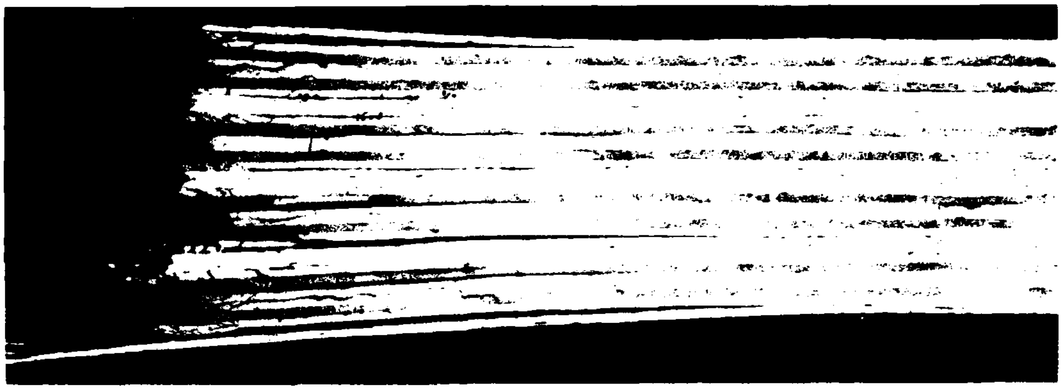


N10-8-1A 10X

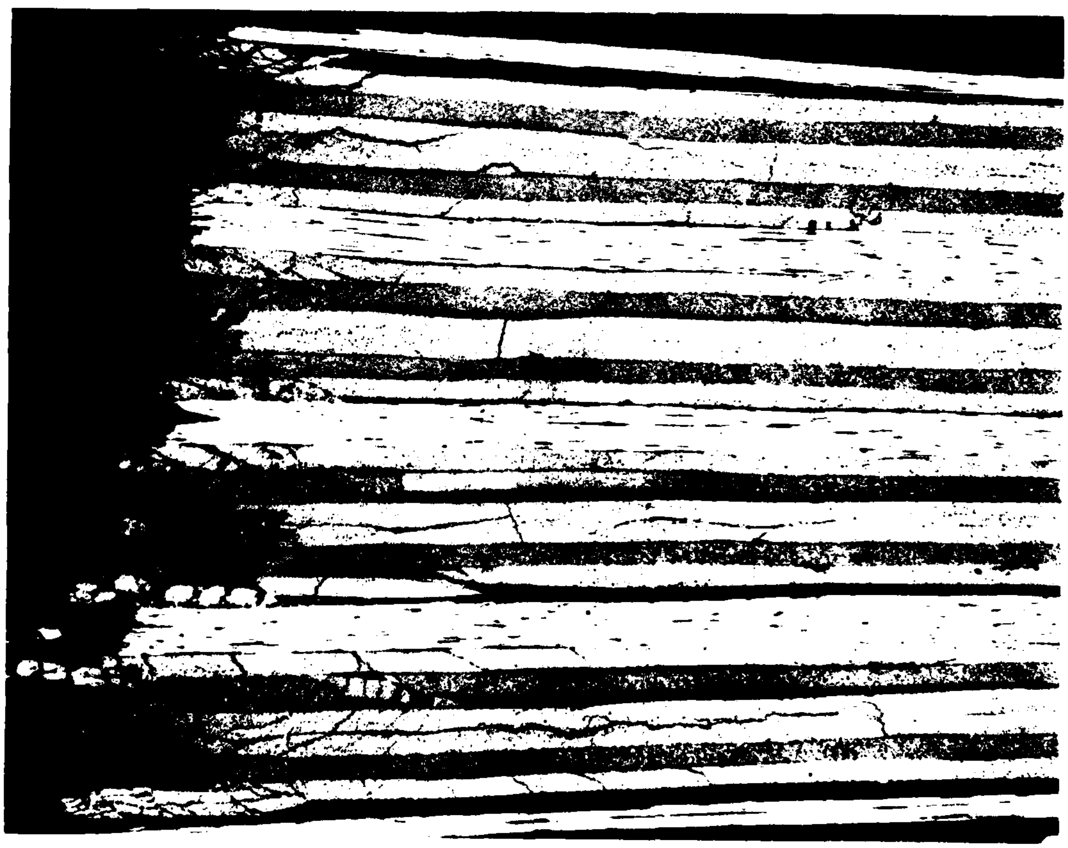


N10-8-2A 25X

LOCATION: 1.68 IN. DAMAGE LENGTH: 0.933



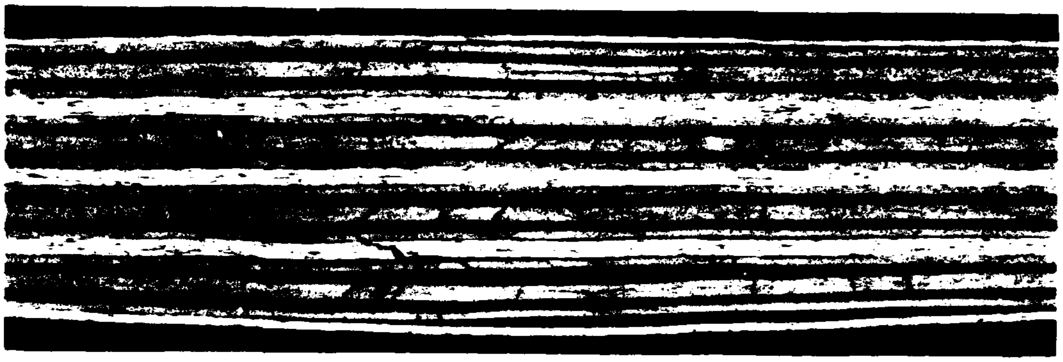
N19-8-1B 10X



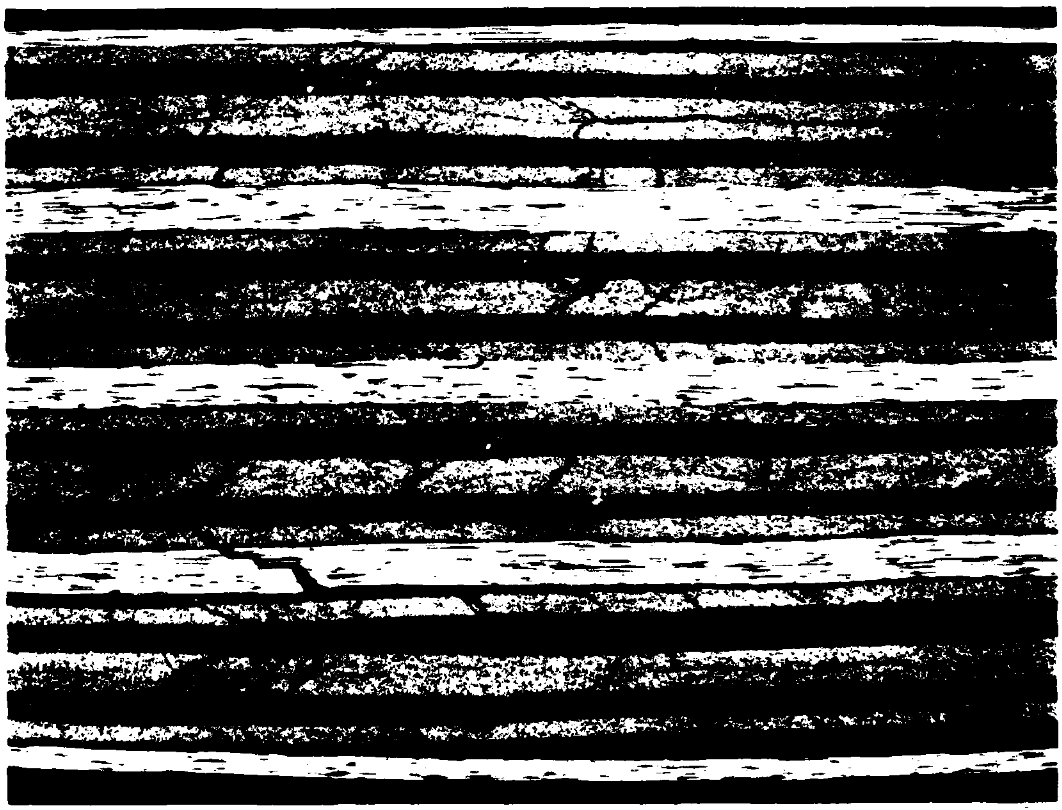
N19-8-2B 25X

LOCATION: 1.68 IN. DAMAGE LENGTH: 0.033

LOCATION: 1.78 IN. DAMAGE LENGTH: 0.888



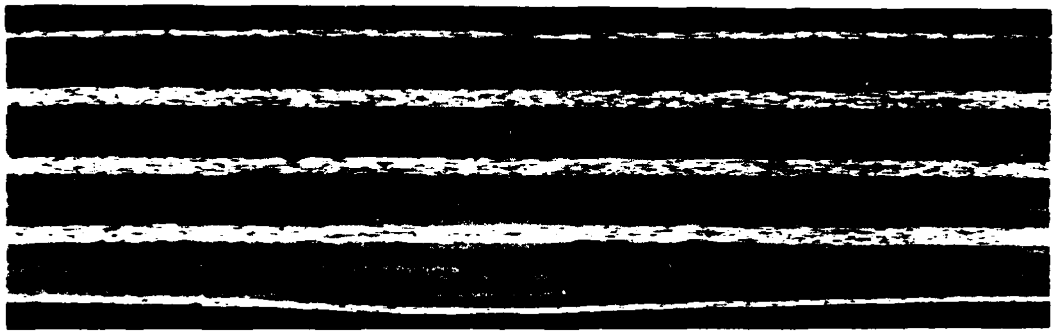
N19-9-1 10X



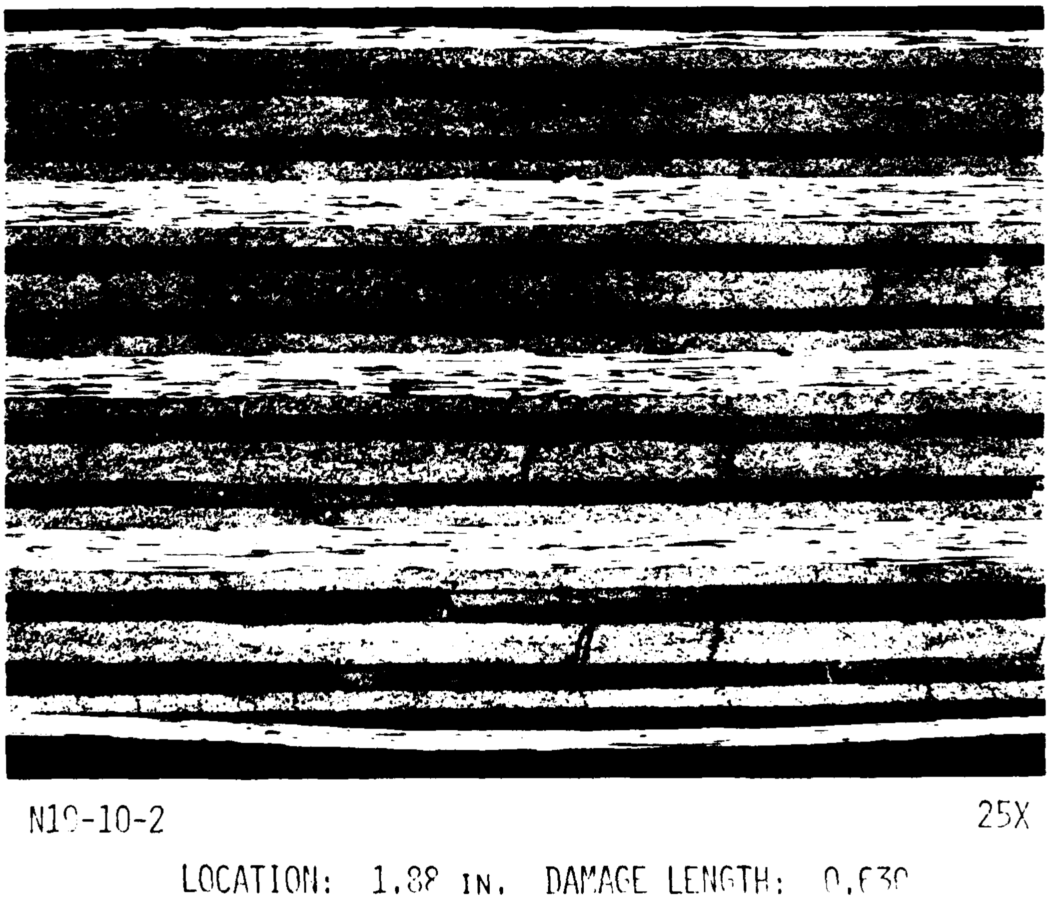
N19-9-2 25X

B-SCAN AT 1.70 IN.

0154



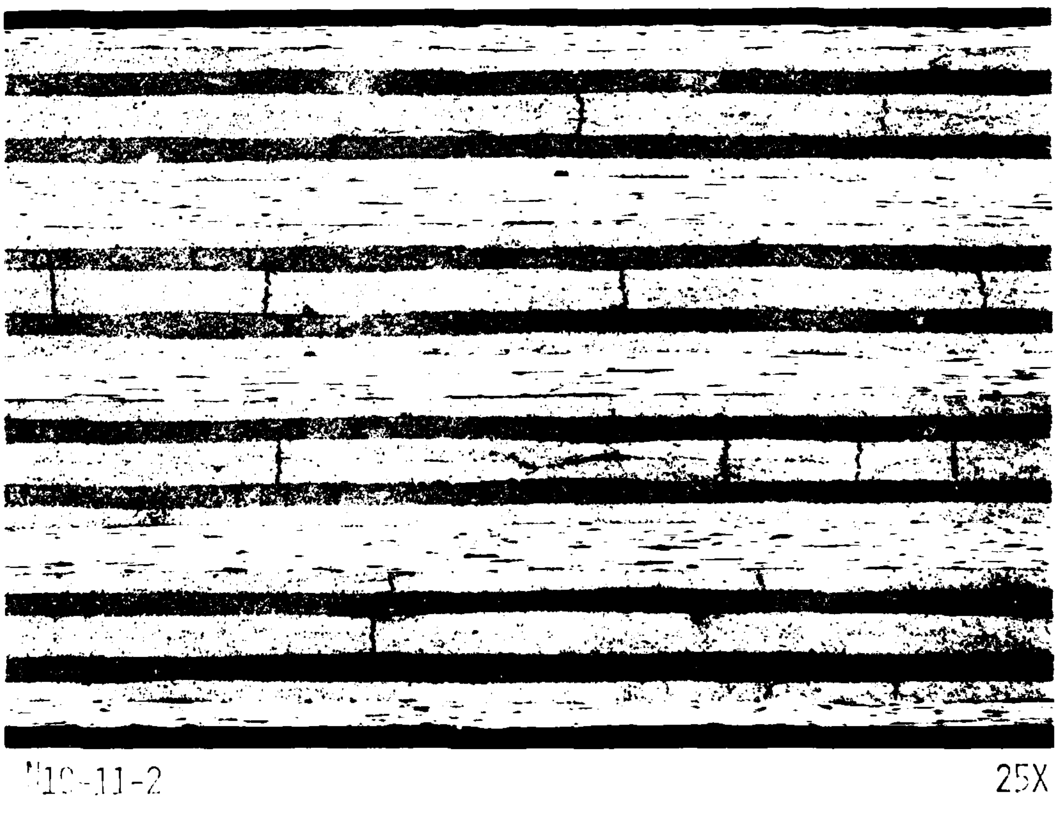
N19-10-1 10X



N19-10-2 25X

LOCATION: 1.88 IN. DAMAGE LENGTH: 0.630

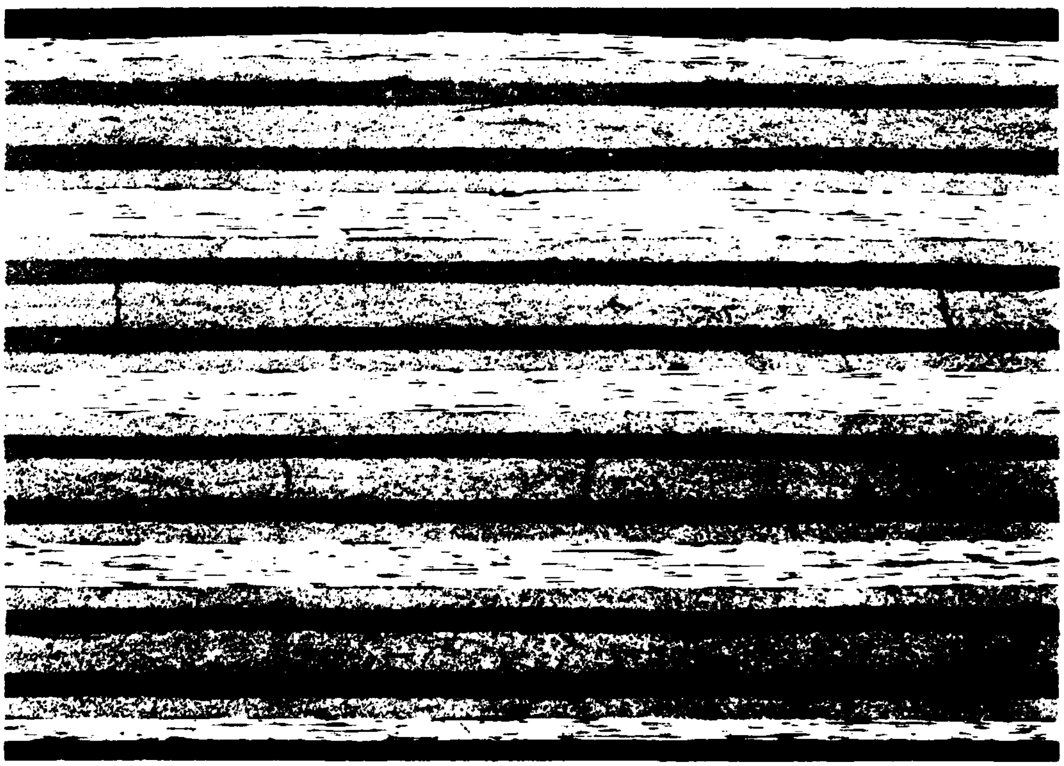
N19-11-1 10X



N19-11-2 25X

LOCATION: 1.98 IN. DAMAGE LENGTH: 0.011

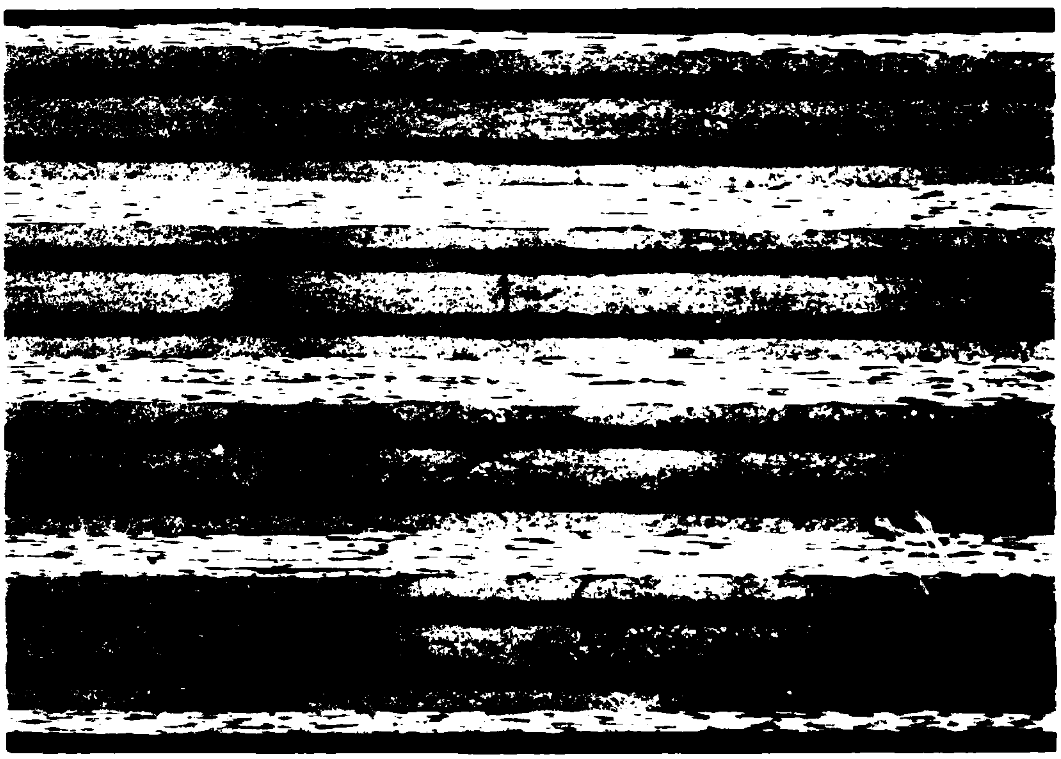
M19-12-1 10X



M19-12-2 25X

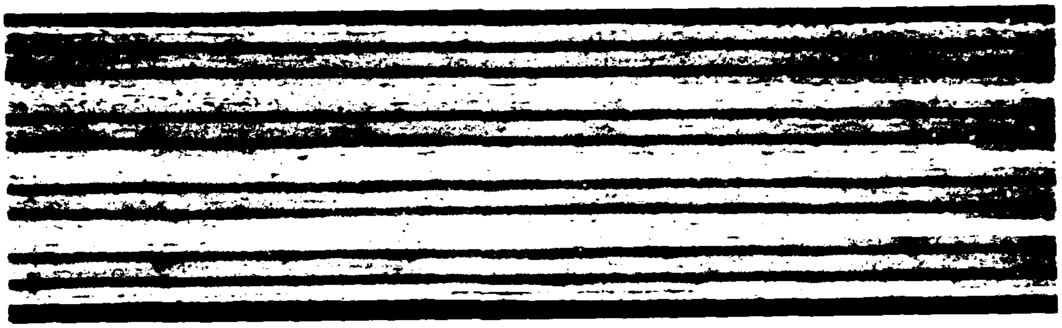
LOCATION: 2.08 IN. DAMAGE LENGTH: 0.562

N19-13-1 10X

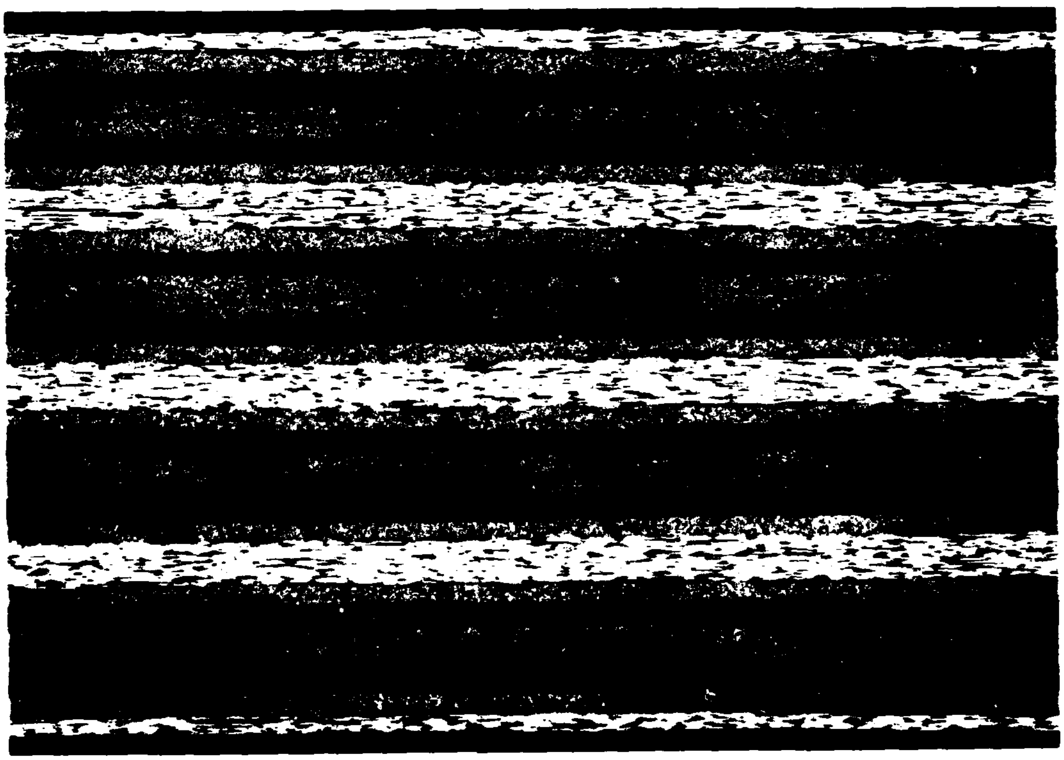


N19-13-2 25X

LOCATION: 2.18 IN. DAMAGE LENGTH: 0.538

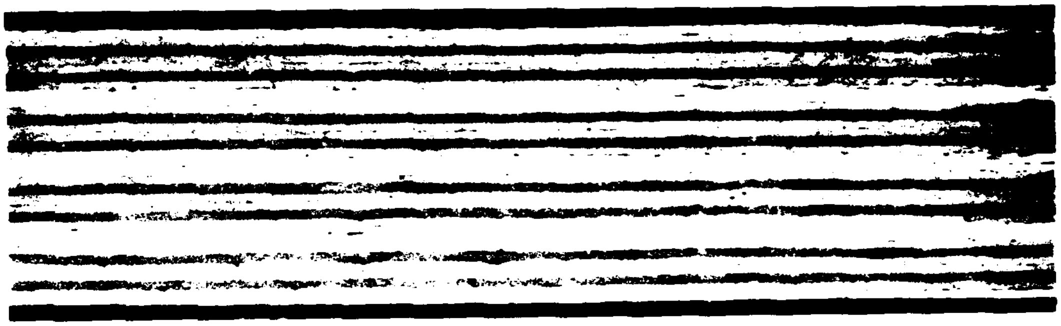


N19-14-1 10X

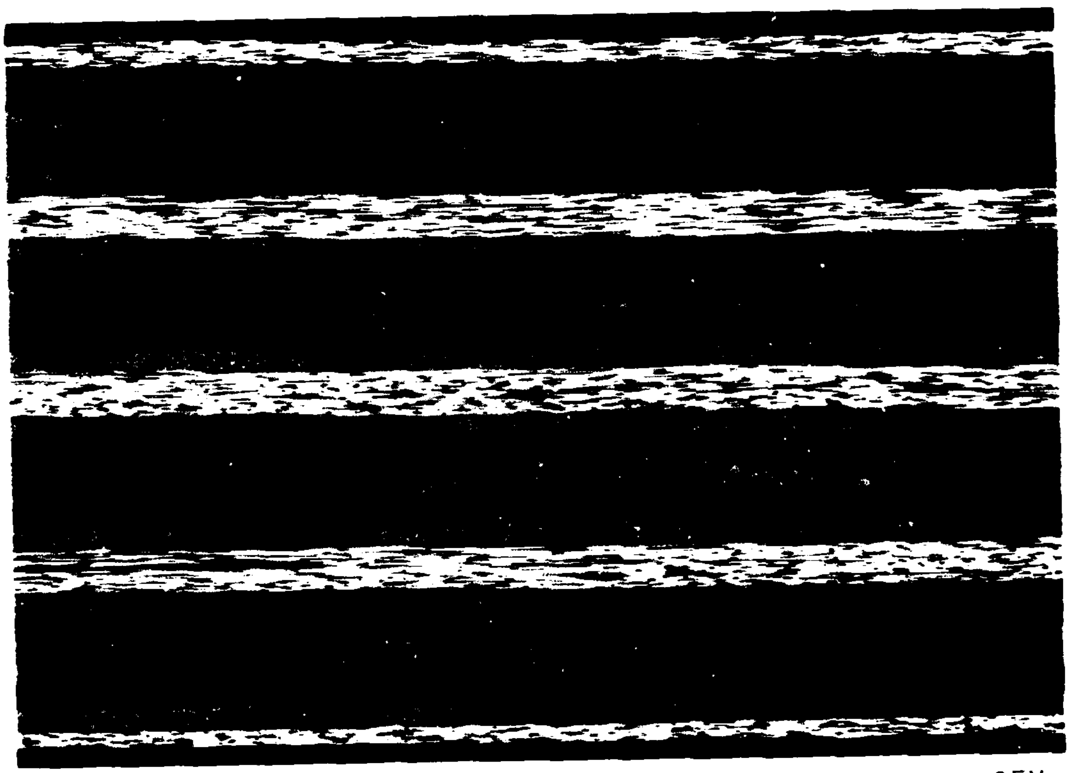


N19-14-2 25X

LOCATION: 2.28 IN. DAMAGE LENGTH: 0.2]4

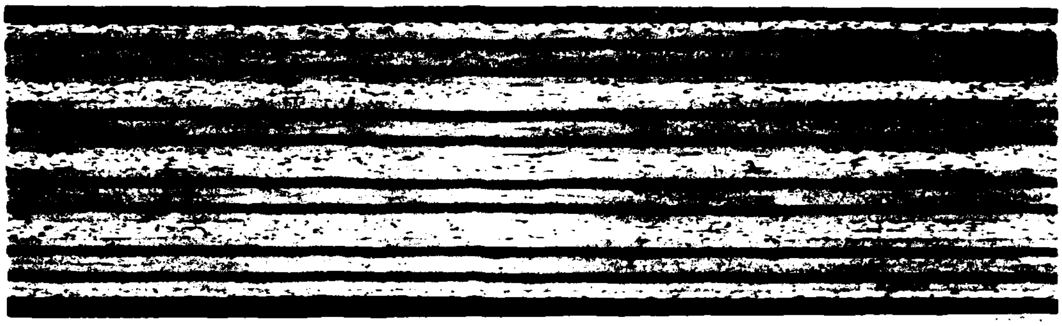


N19-15-1 10X

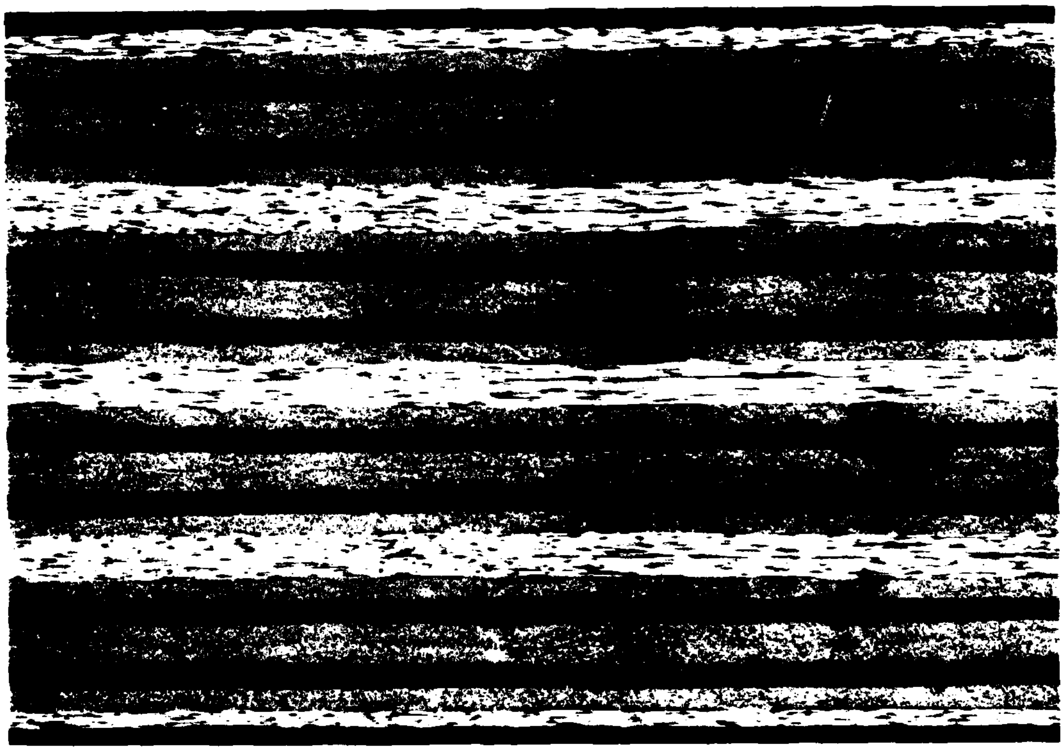


N19-15-2 25X

LOCATION: 2.38 IN. DAMAGE LENGTH: 0.078

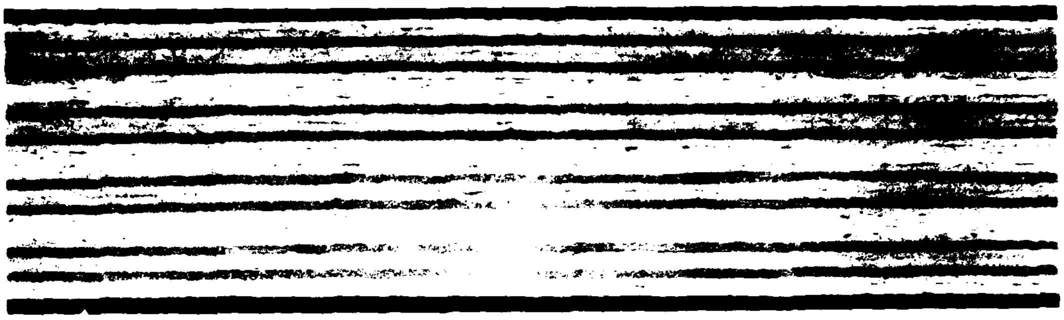


N19-16-1 10X

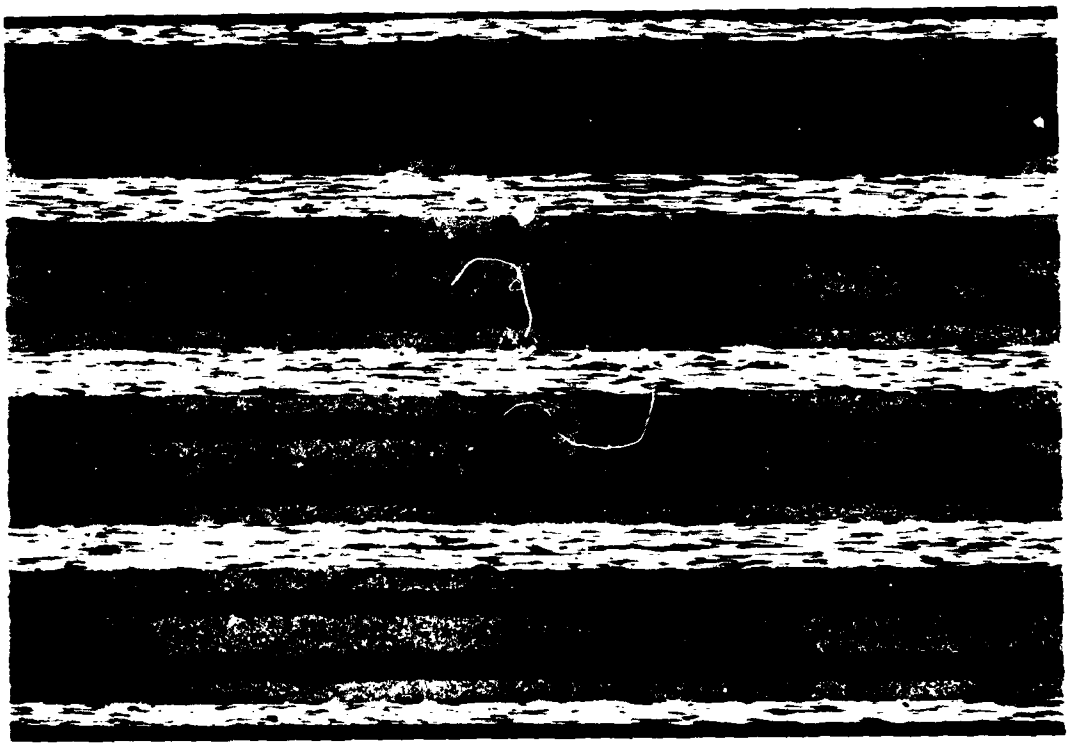


N19-16-2 25X

LOCATION: 2.48 IN. DAMAGE LENGTH: 0.122



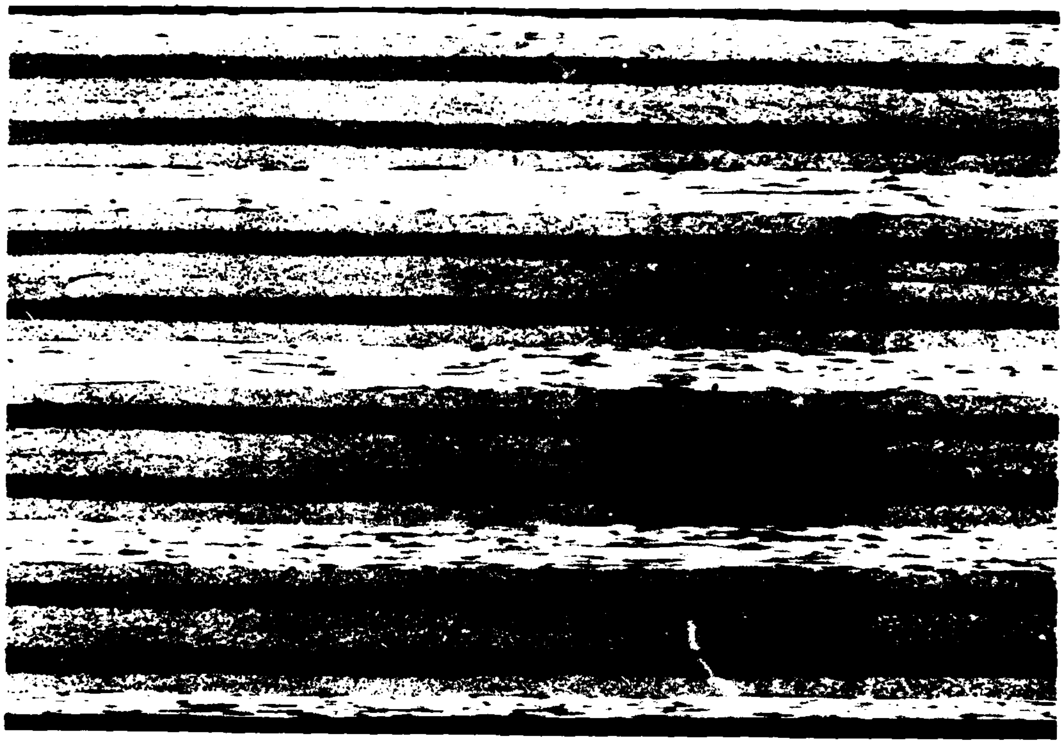
N19-17-1 10X



N19-17-2 25X

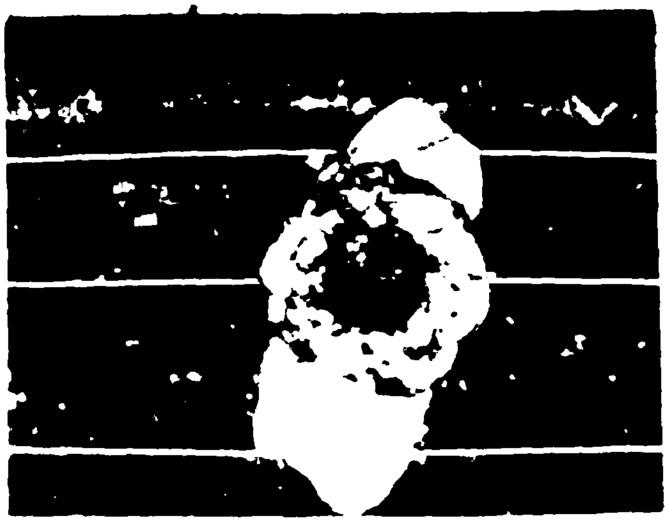
LOCATION: 2.58 IN. DAMAGE LENGTH. 0.108

N19-18-1 10X

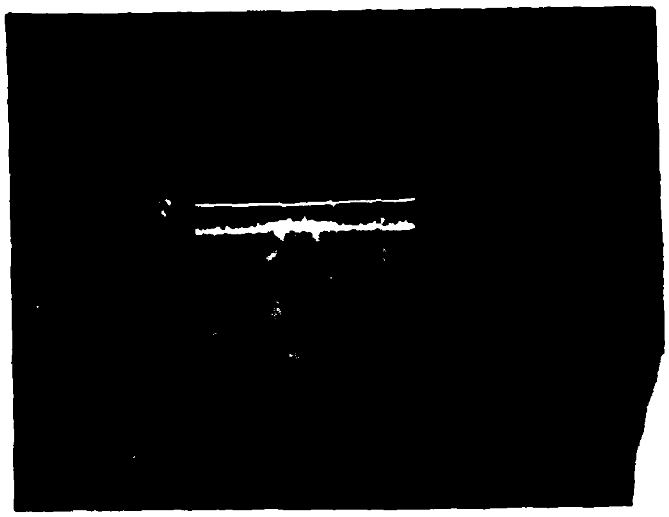


N19-18-2 25X

LOCATION: 2.63 IN. DAMAGE LENGTH: ONE TRANS CRACK THRU TWO PLYS



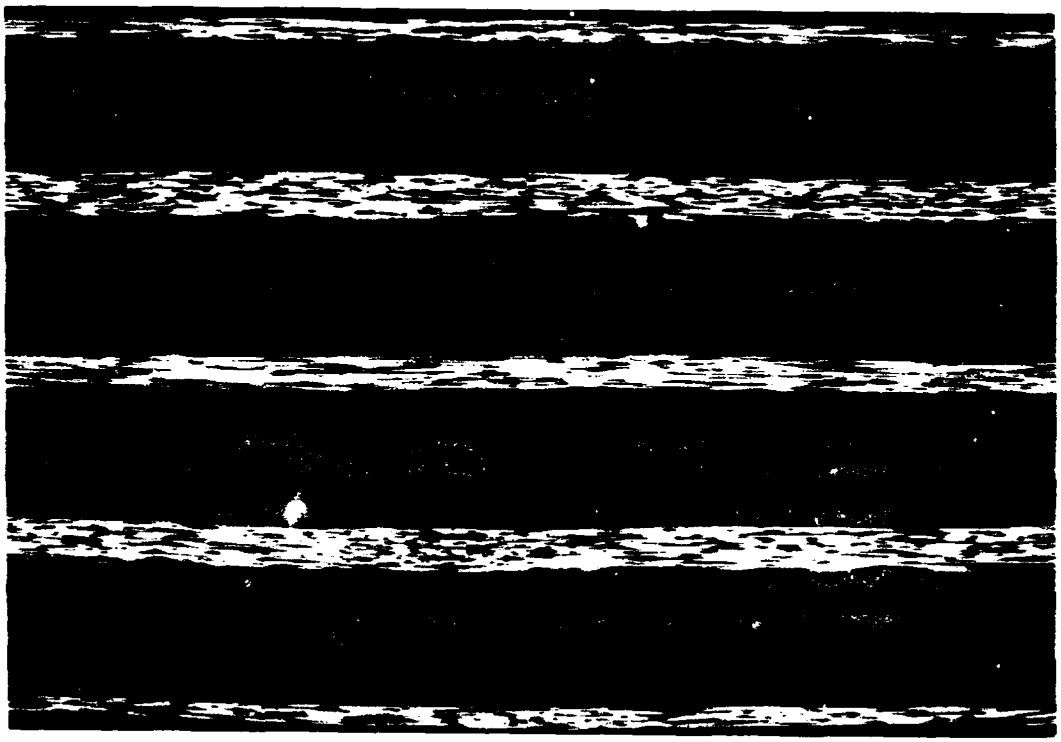
C-SCAN



CUMULATIVE B-SCAN

32-PLY SPEC: JC-30 N_5 = 28,000 CYCLES

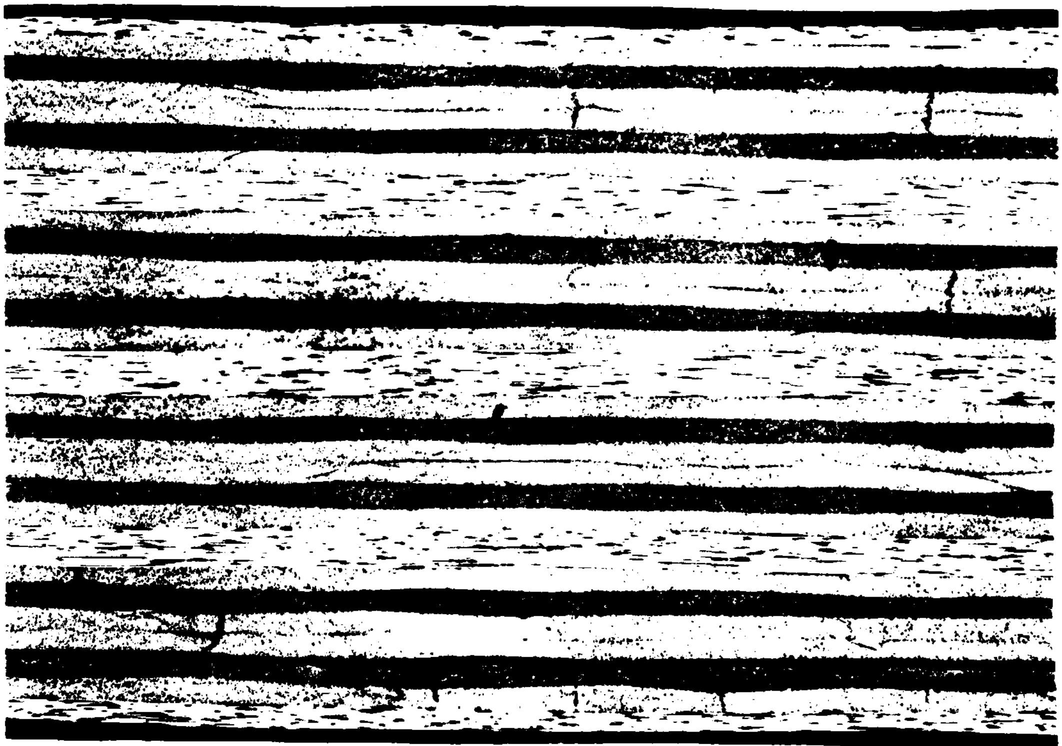
J30-1-1 10X



J30-1-2 25X

LOCATION: 0.84 IN. DAMAGE LENGTH: 0.217

J30-2-1 10X

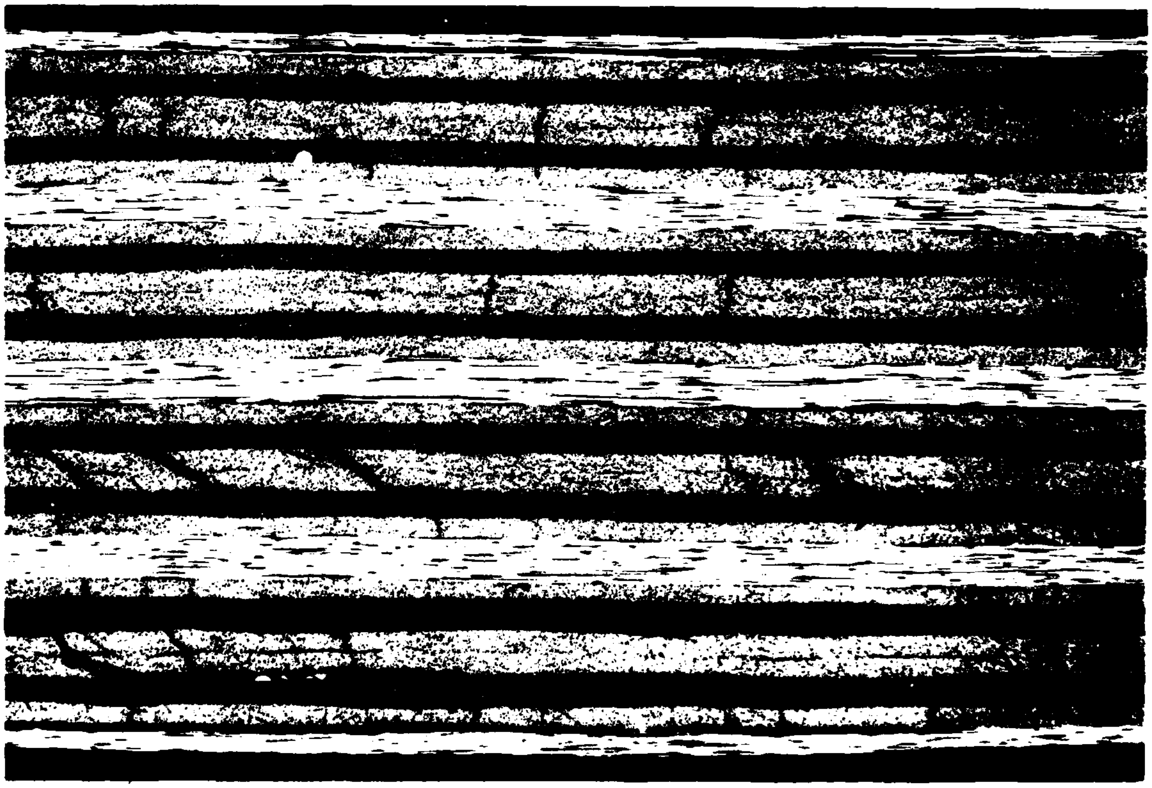


J30-2-2 25X

B-SCAN AT 0.98 IN.

LOCATION: 0.94 IN. DAMAGE LENGTH: 0.657

J30-3-1 10X



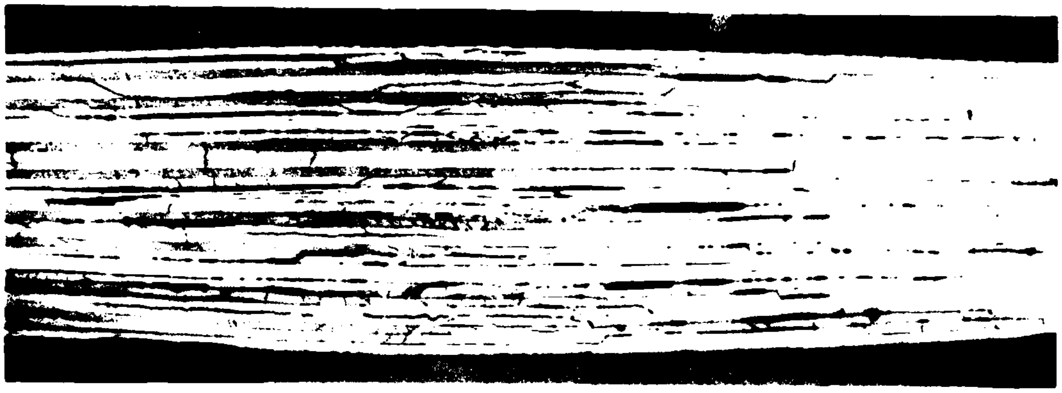
J30-3-2 25 X

LOCATION: 1.04 IN. DAMAGE LENGTH: 0.727

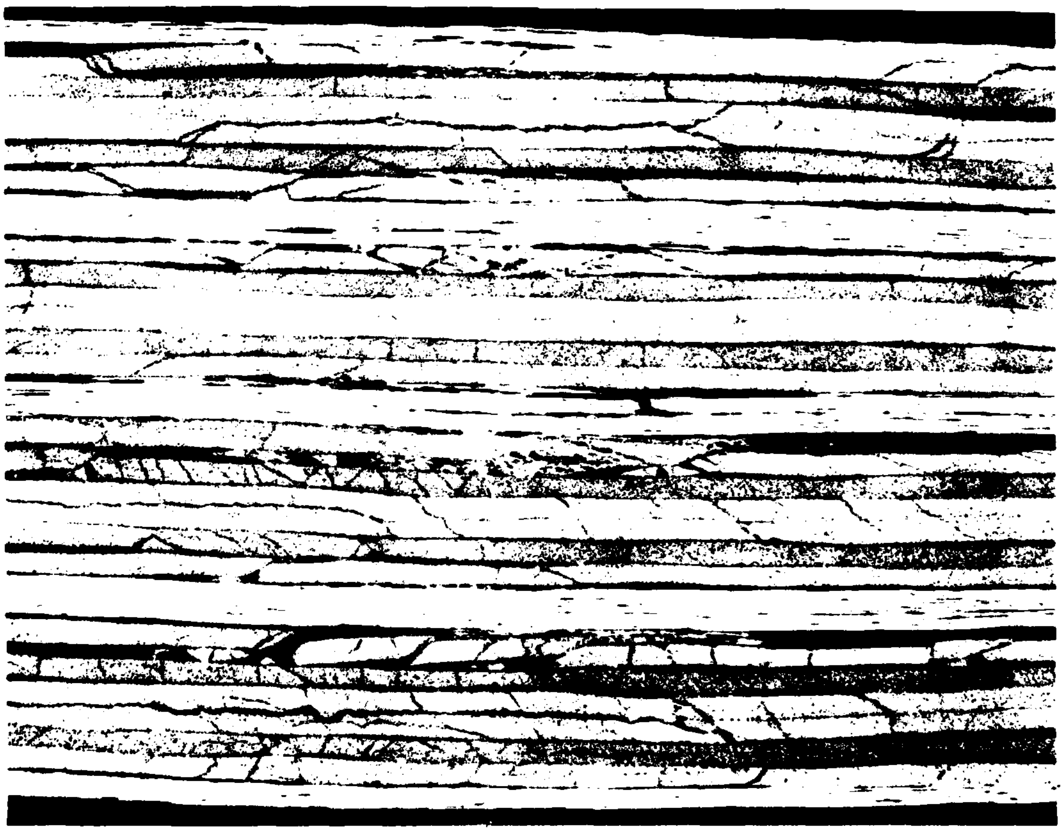
J30-4-1 10 X

J30-4-2 25X

LOCATION: 1.14 IN. DAMAGE LENGTH: 0.746



J30-5-1 10X



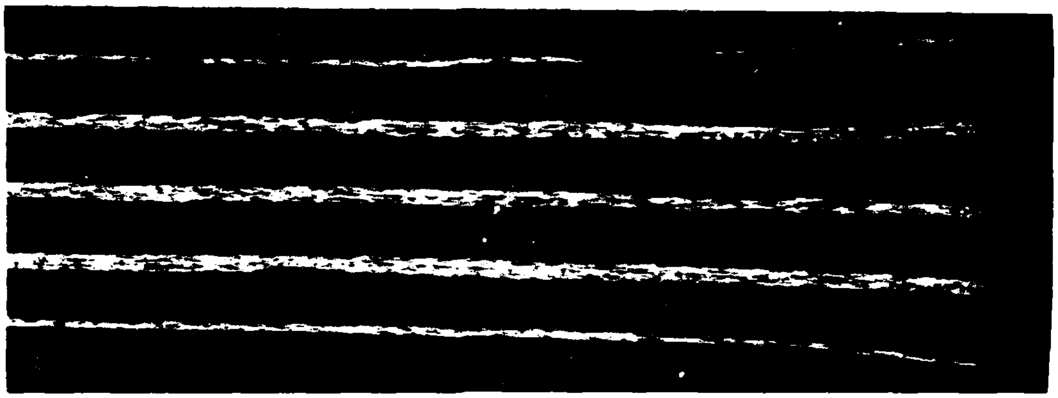
J30-5-2 25X

LOCATION: 1.24 IN. DAMAGE LENGTH: 0.764

J30-6-1A 10X

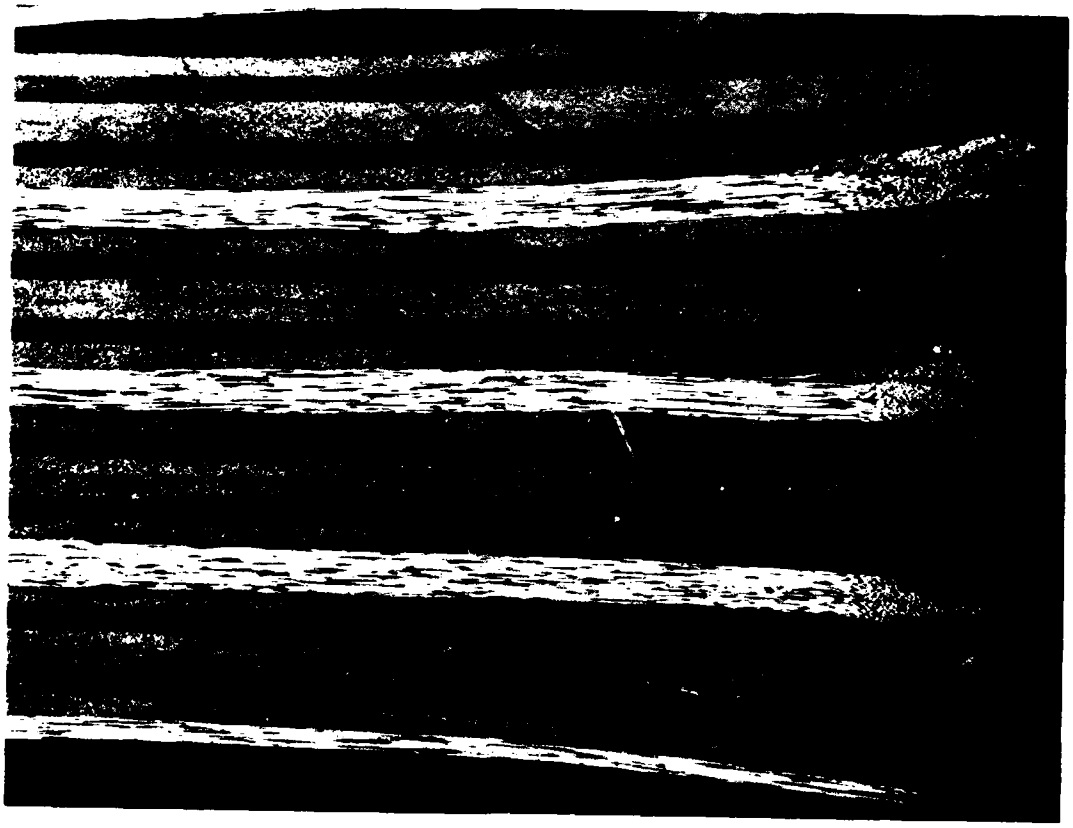
J30-6-1A 25X

LOCATION: 1.34 IN. DAMAGE LENGTH: 0.067



J30-6-1B

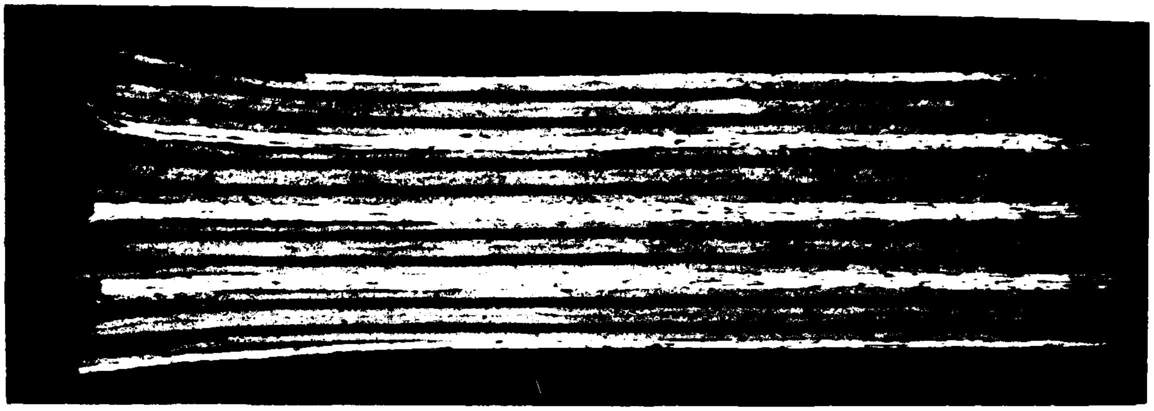
10X



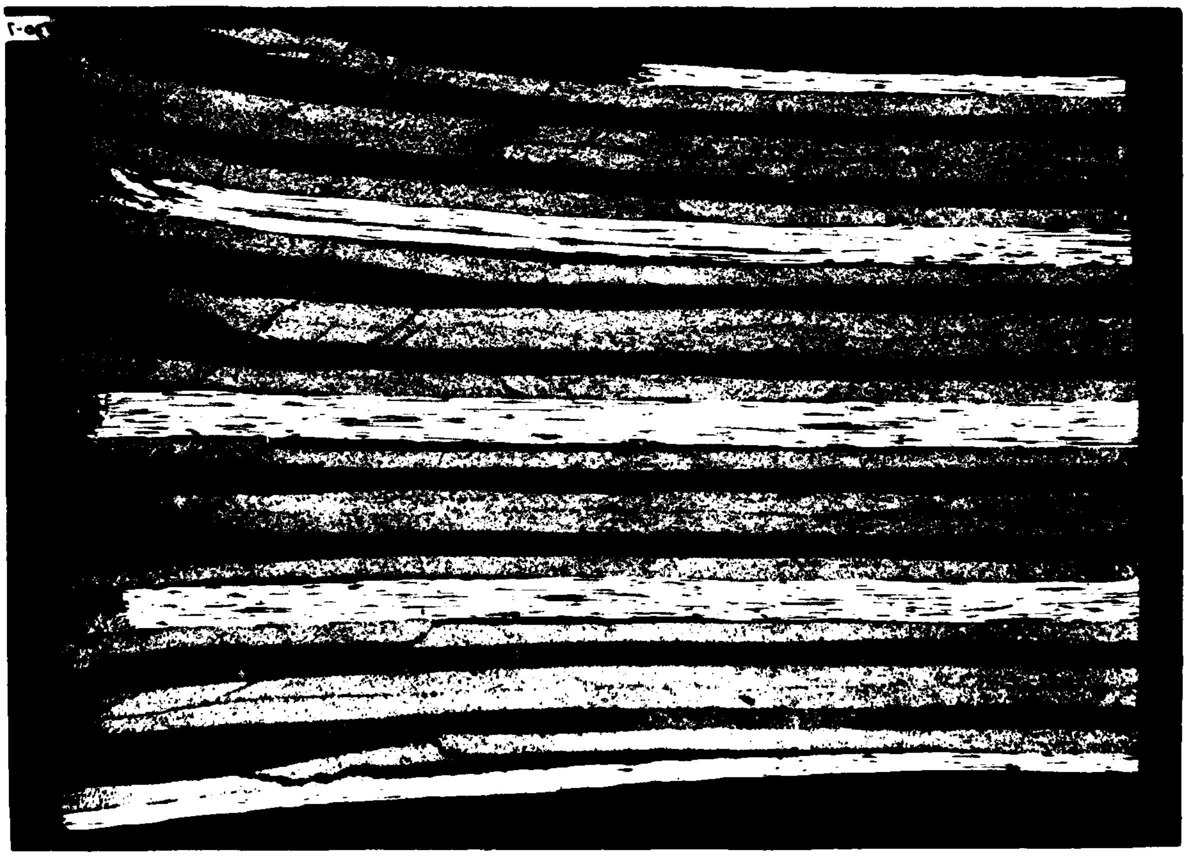
J30-6-2B

25X

LOCATION: 1.34 IN. DAMAGE LENGTH: 0.967

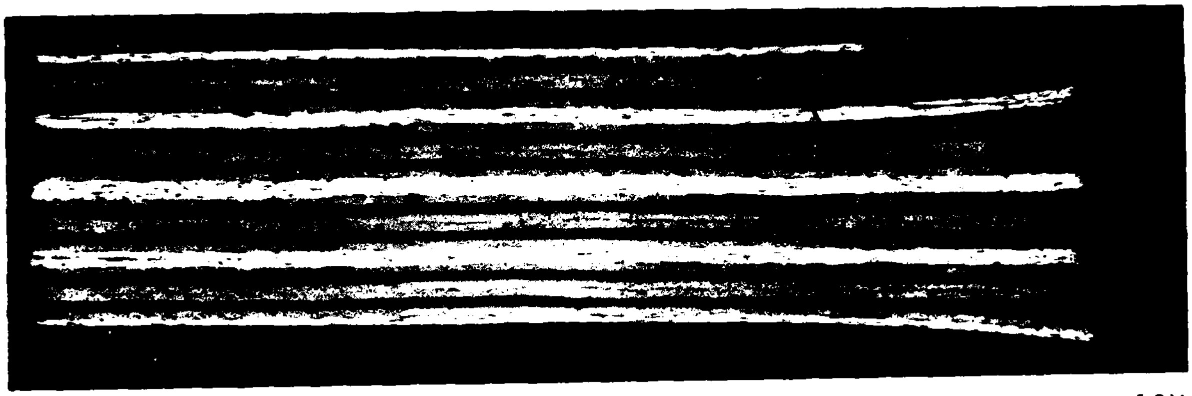


J30-7-1A 10X

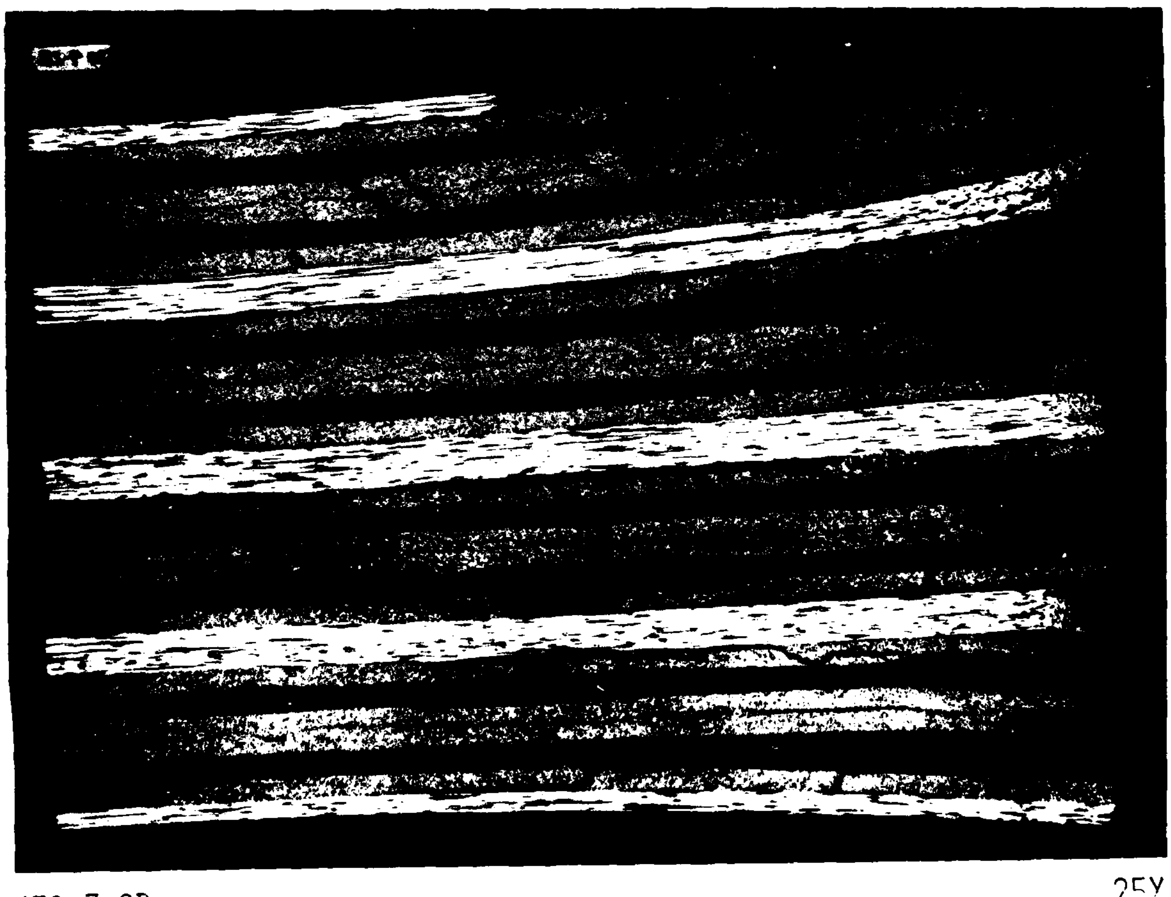


[illegible] 25X

LOCATION: 1.05 IN. DAMAGE LENGTH: 1.[illegible]

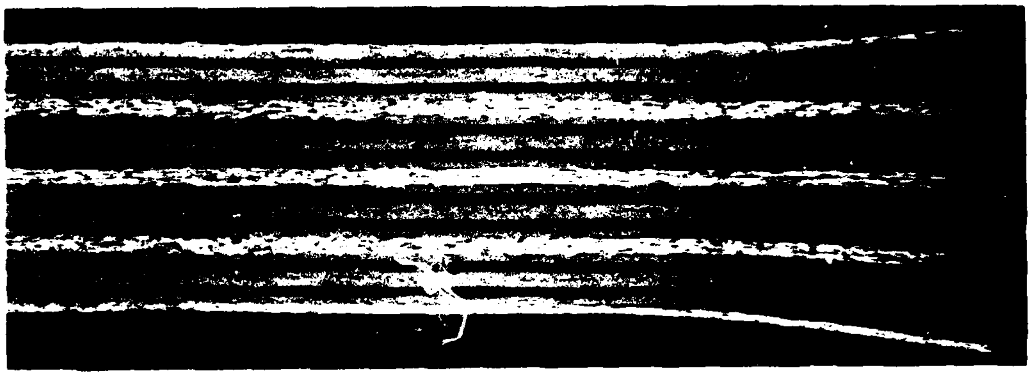


J30-7-1B 10X



J30-7-2B 25X

LOCATION: 1.05 IN. DAMAGE LENGTH: 1.102

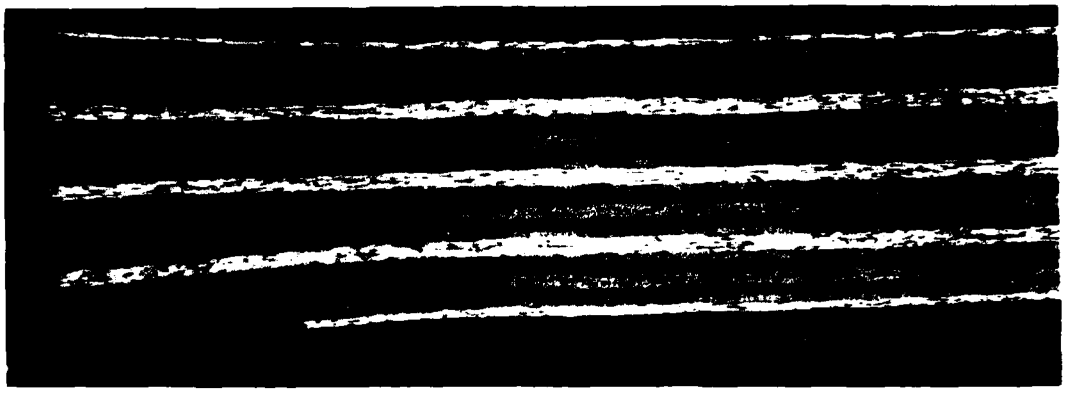


J30-8-1A 10X

J30-8-2A 25X

B-SCAN AT CENTER

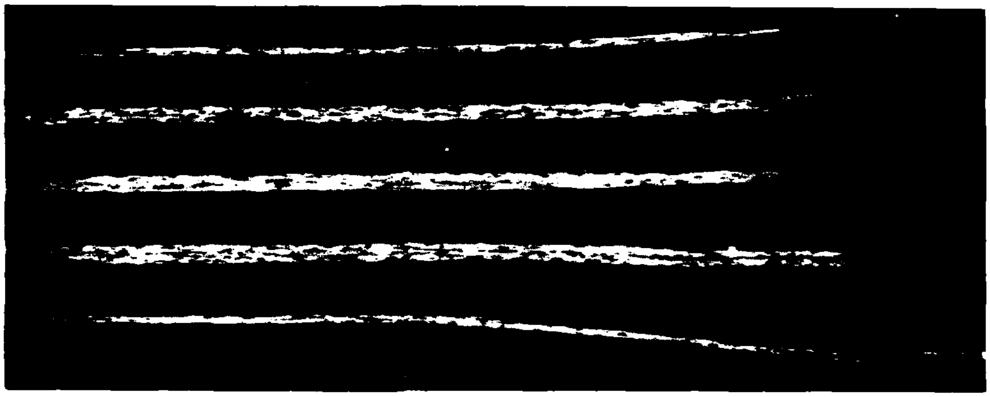
LOCATION: 1.54 IN. DAMAGE LENGTH: 0.850



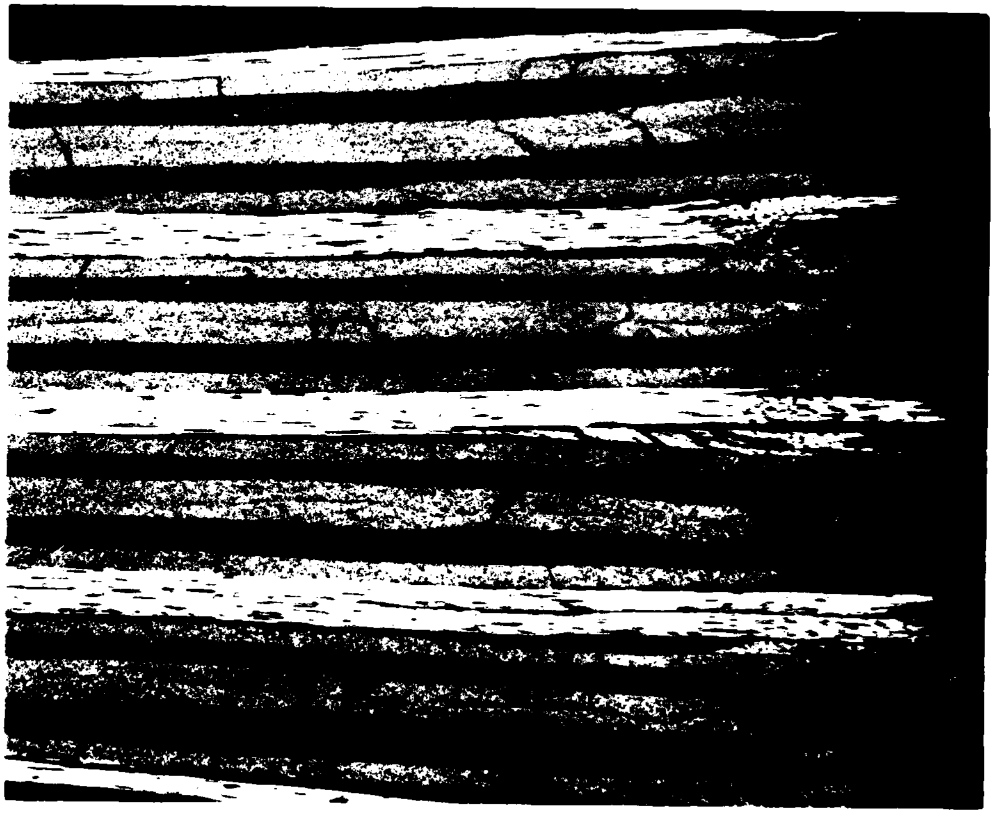
J30-8-1B 10X

J30-8-2B 25 X

LOCATION: 1.54 IN. DAMAGE LENGTH: 0.850

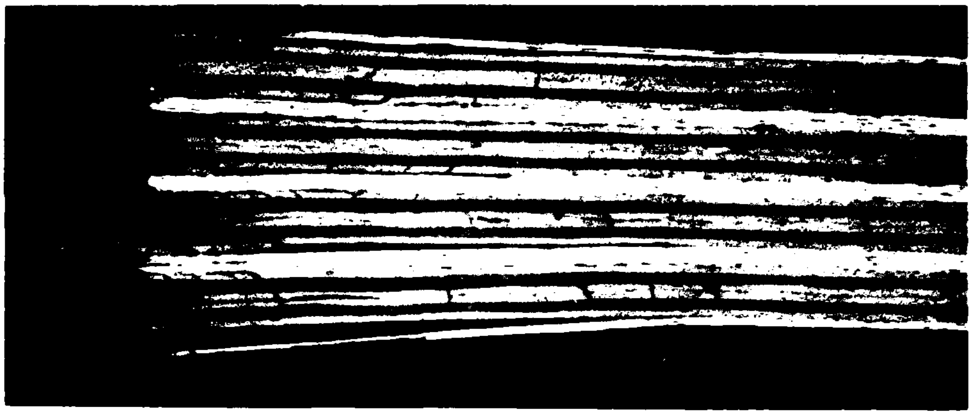


J30-9-1A 10X

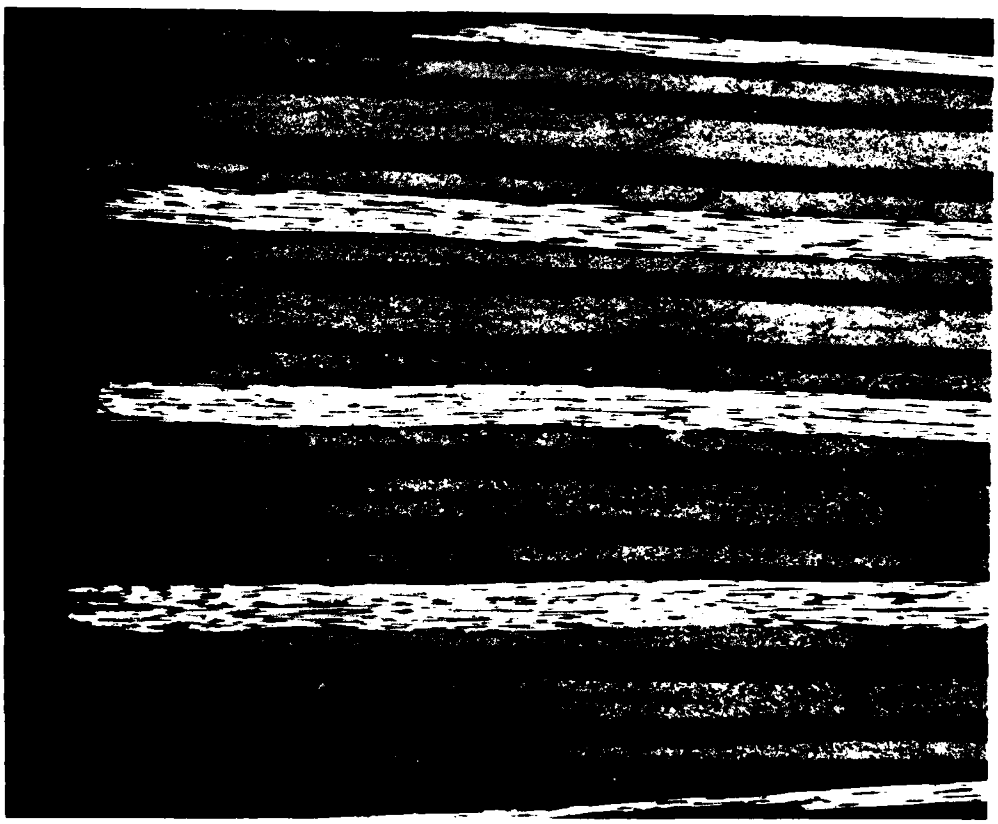


J30-9-2A 25X

LOCATION: 1.64 IN. DAMAGE LENGTH 0.843

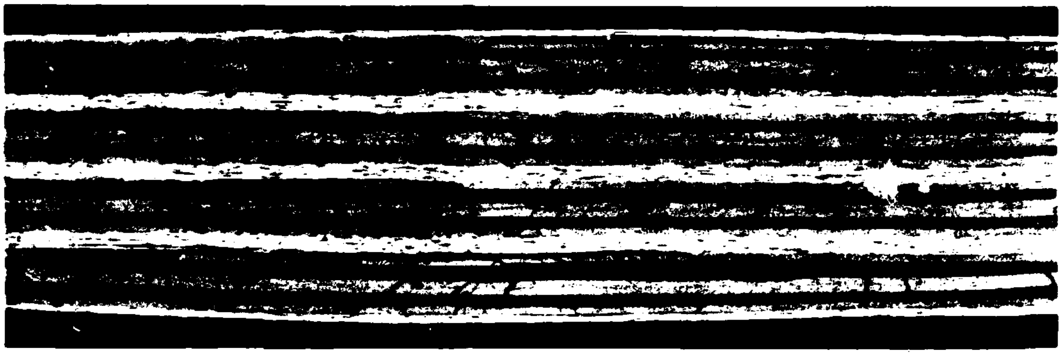


J30-9-1B 10X

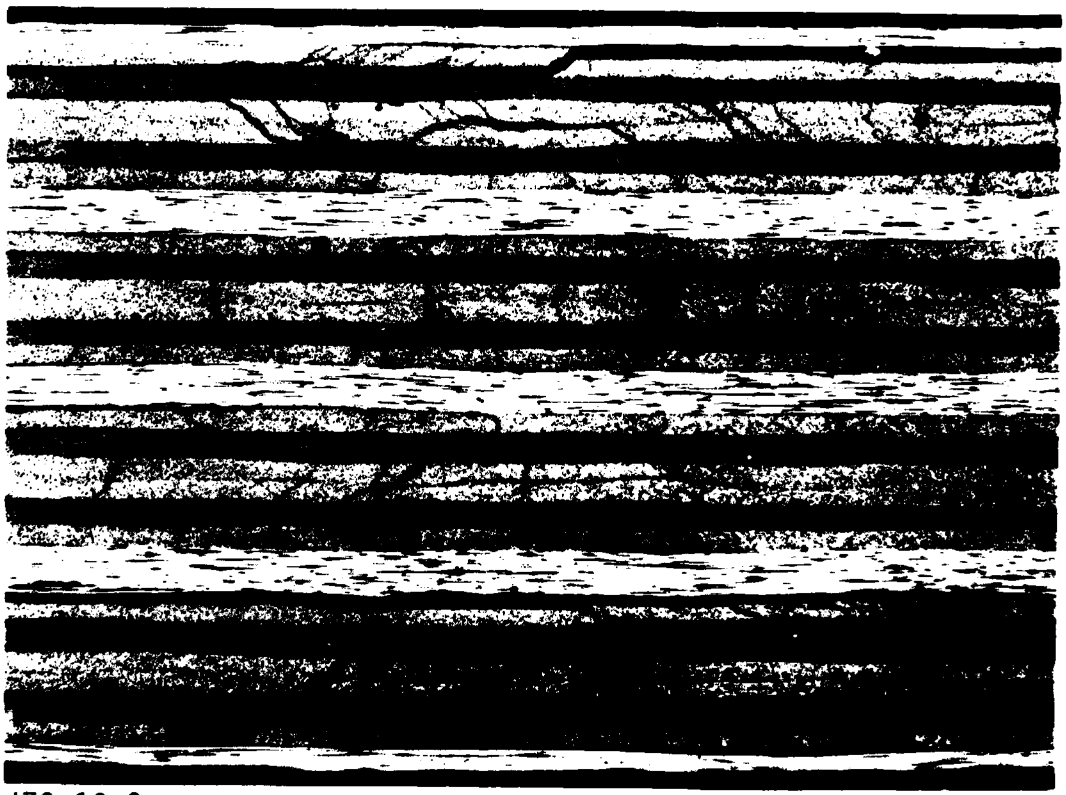


J30-9-2B 25X

LOCATION: 1.64 IN. DAMAGE LENGTH 0.843

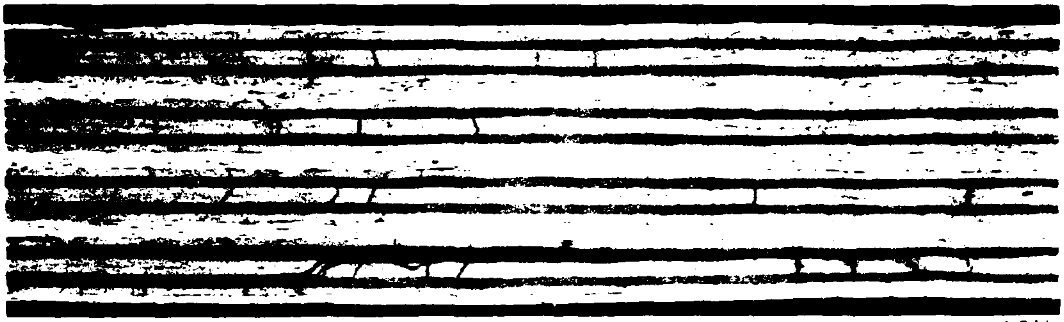


J30-10-1 10X

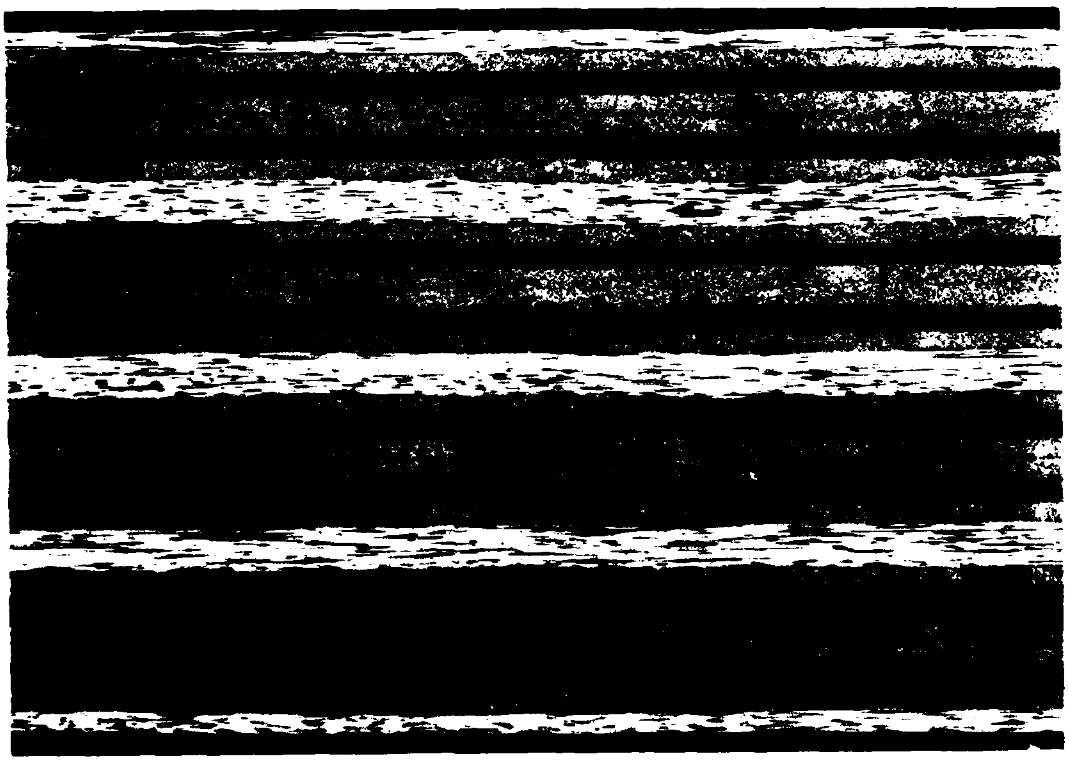


J30-10-2 25X

LOCATION: 1.74 IN. DAMAGE LENGTH: 0.781



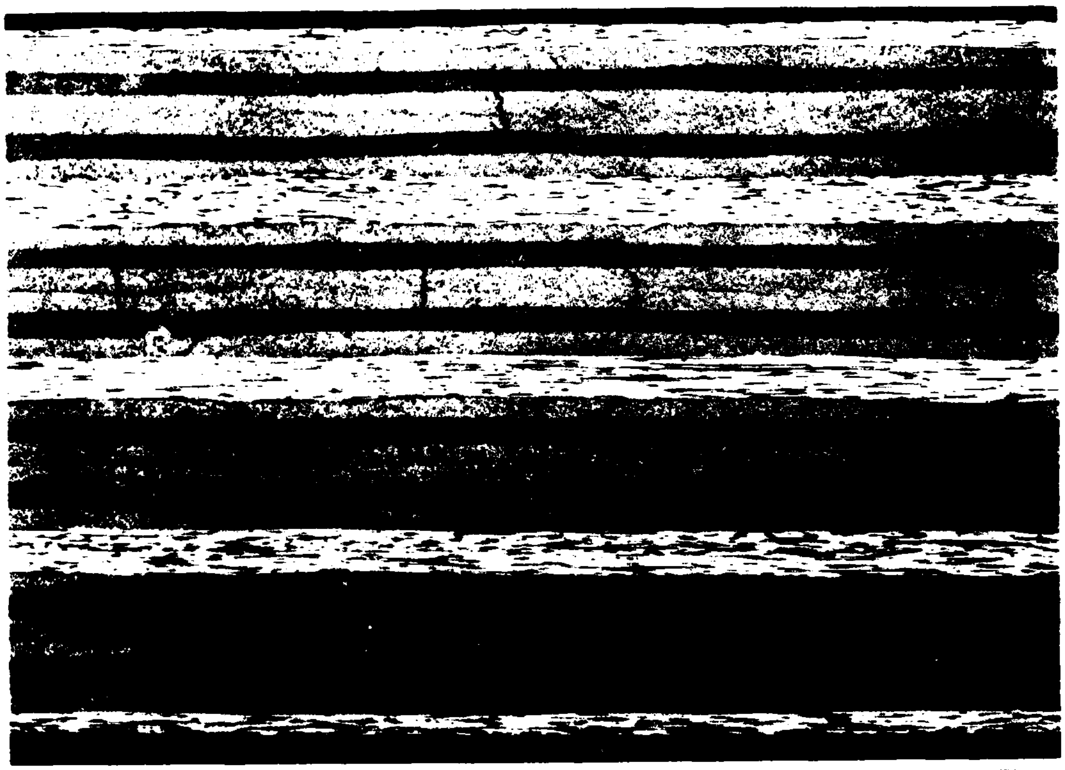
J30-11-1 10X



J30-11-2 25X

LOCATION: 1.84 IN. DAMAGE LENGTH: 0.762

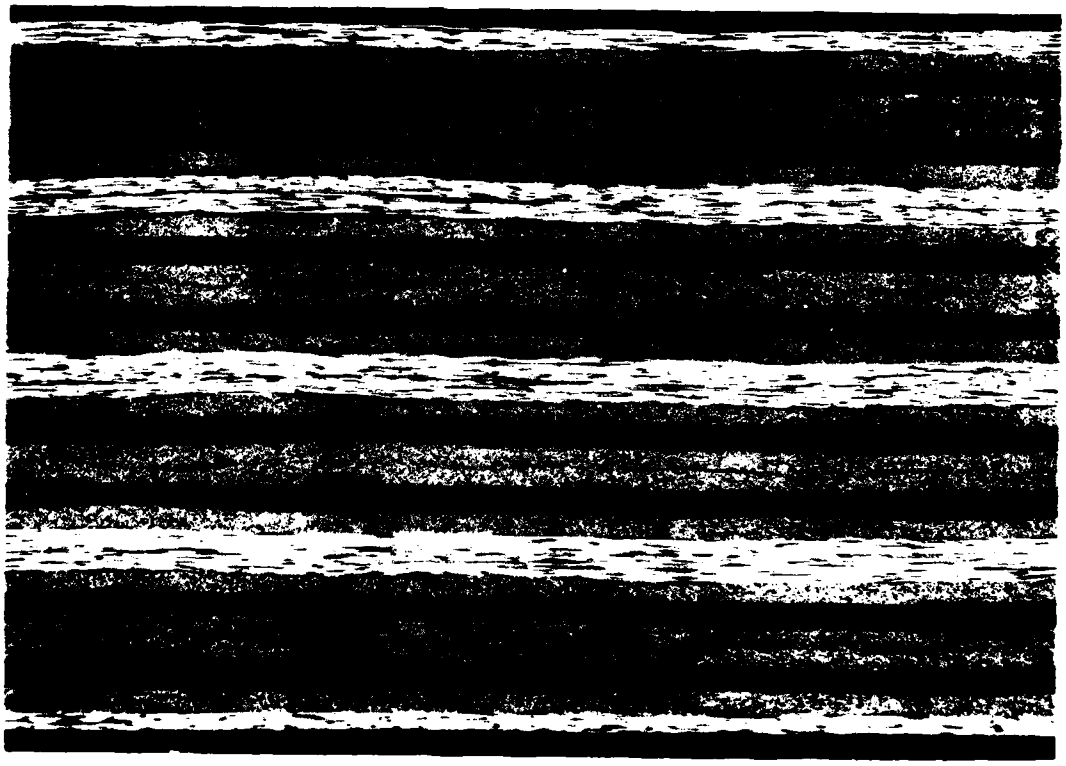
J30-12-1



J30-12-2 25X

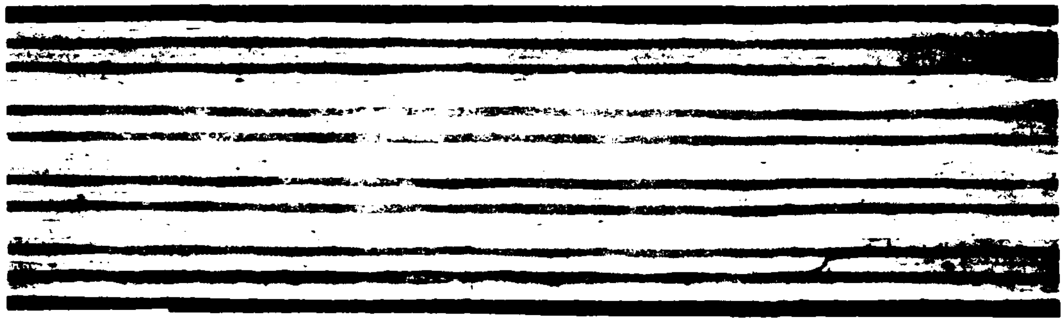
LOCATION: 1.94 IN. DAMAGE LENGTH: 0.743

J30-13-1 10X

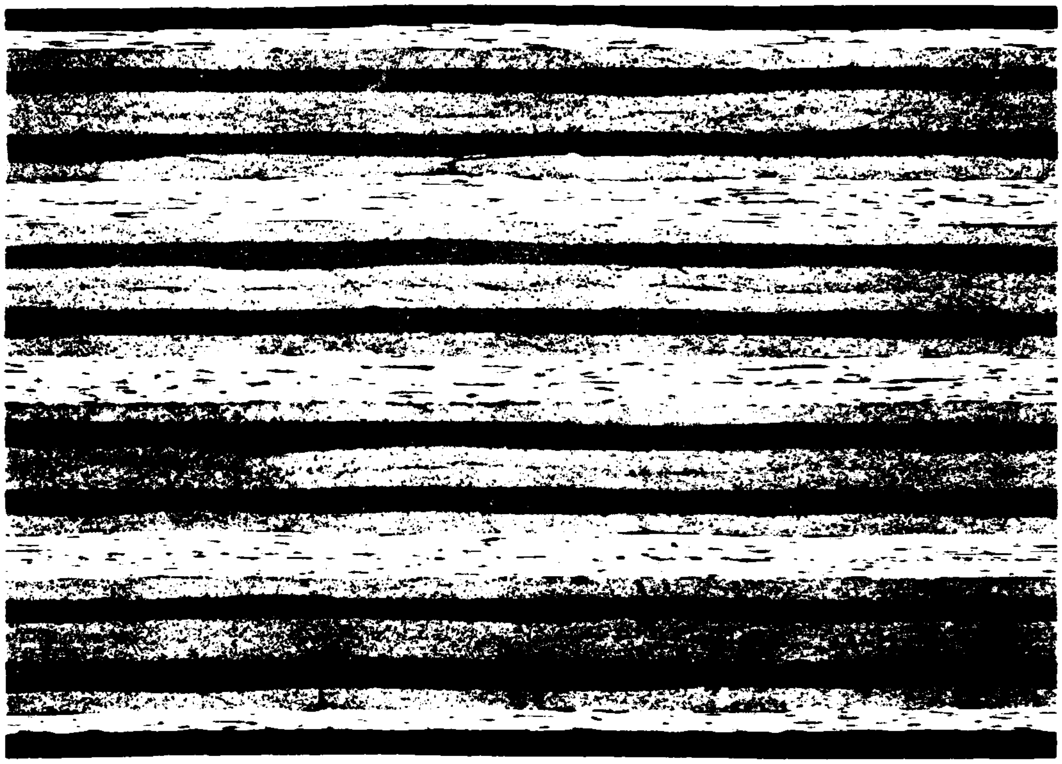


J30-13-2 25X

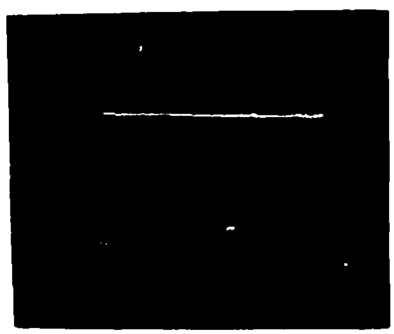
LOCATION: 204 IN. DAMAGE LENGTH: 0.658



J30-14-1



J30-14-2



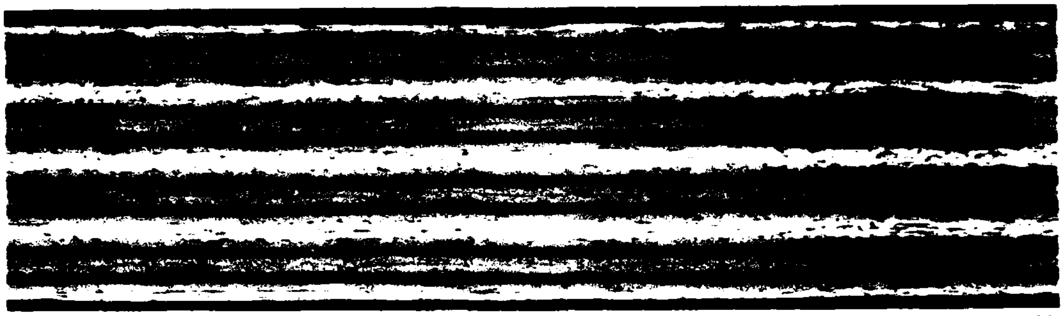
B-SCAN AT 2.16 IN.

LOCATION: 2.14 IN. DAMAGE LENGTH: 0.577

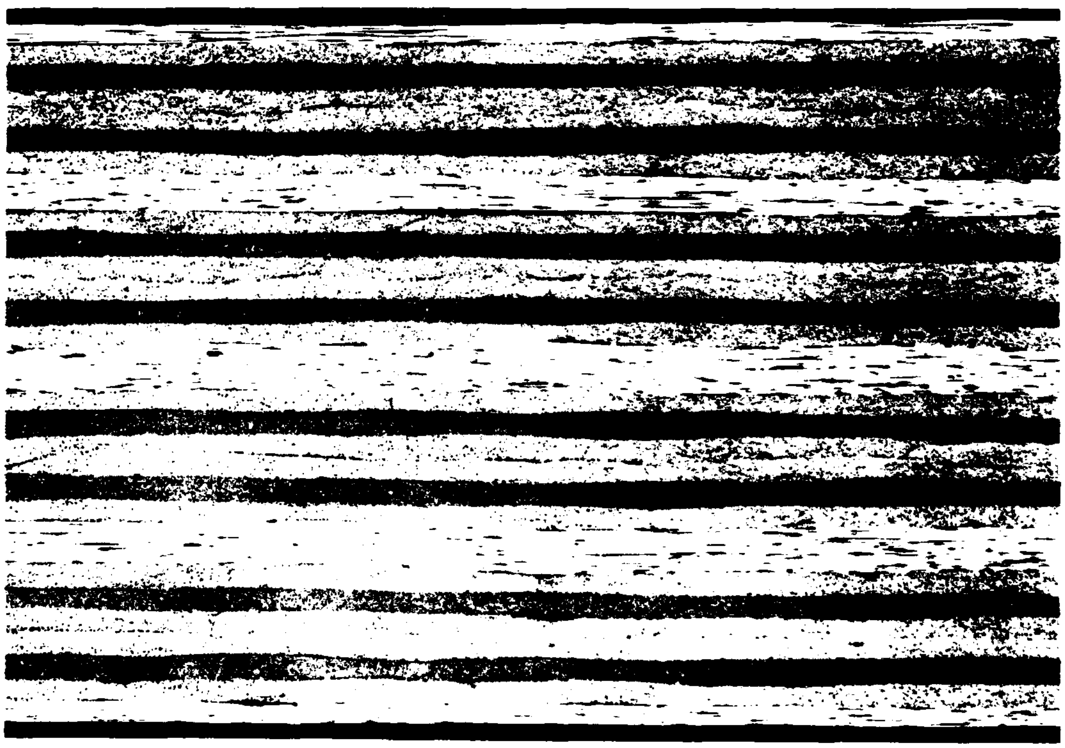
J30-15-1 10X

J30-15-2 25X

LOCATION: 2.24 IN. DAMAGE LENGTH: 0.280



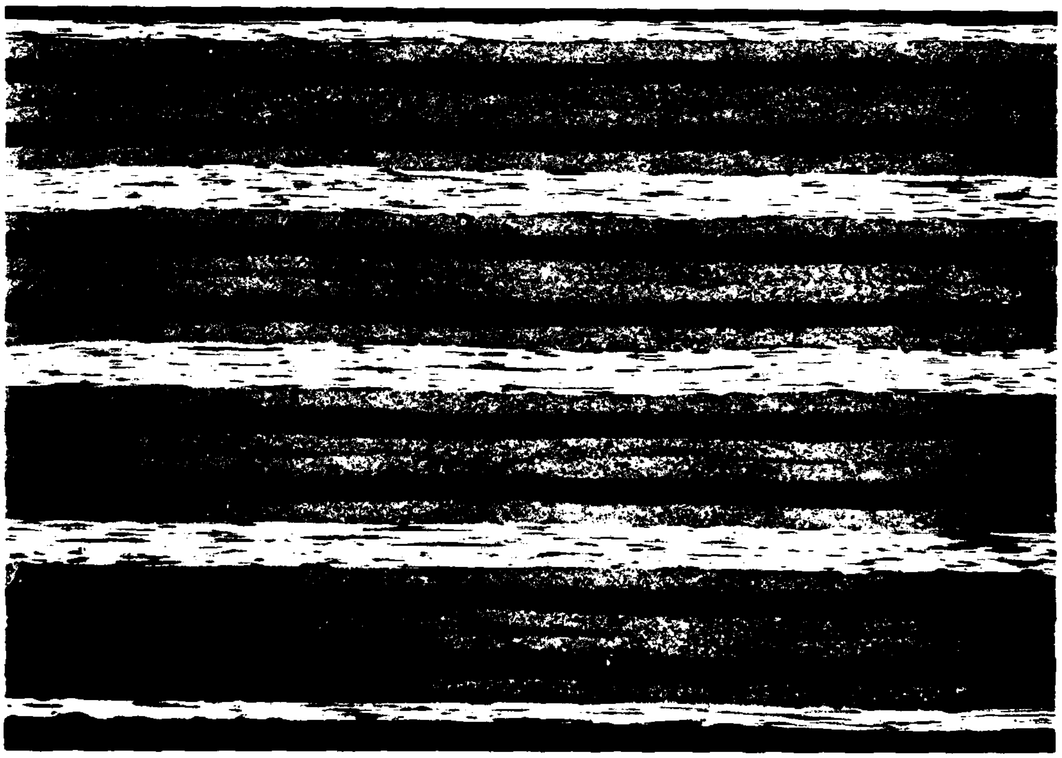
J3C-16-1 10X



J30-16-2 25X

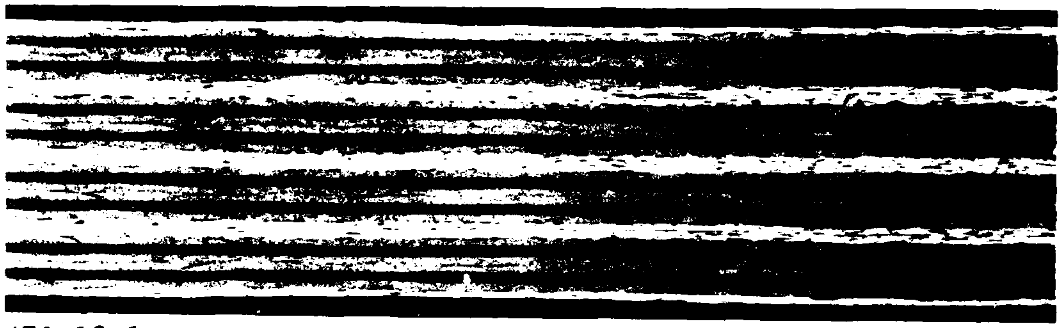
LOCATION: 2.34 IN. DAMAGE LENGTH: ONE TRANS PLY CRACK

J30-17-1: 10X

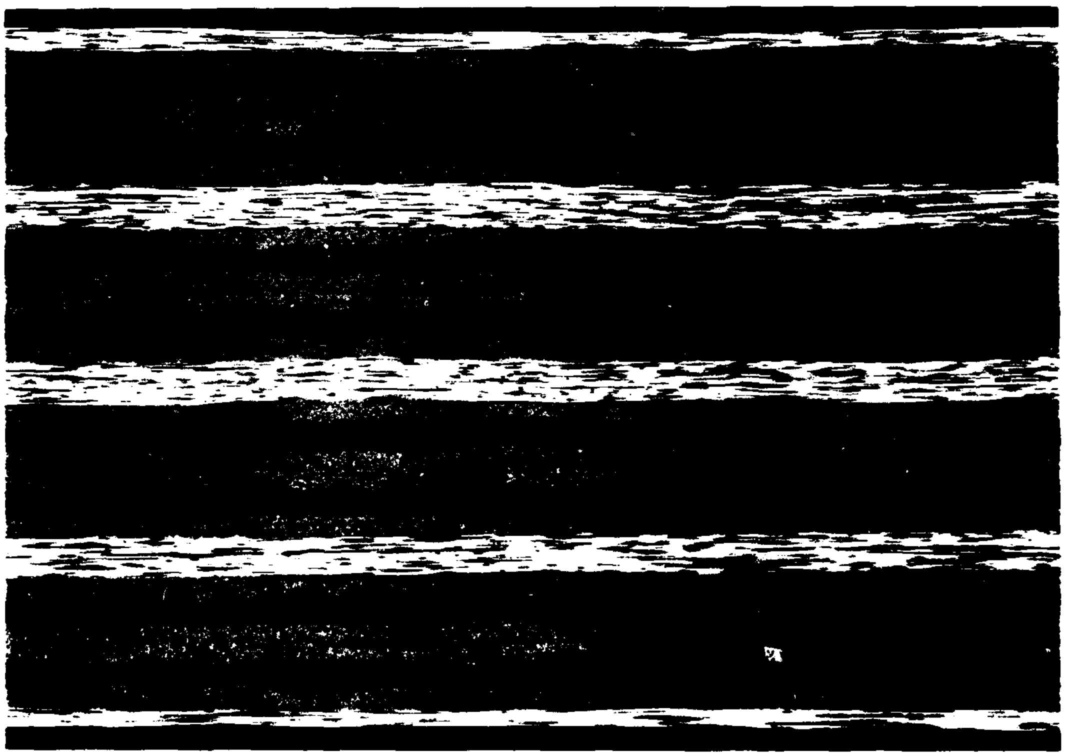


25X

[illegible] ONE TRANS PLY CRACK



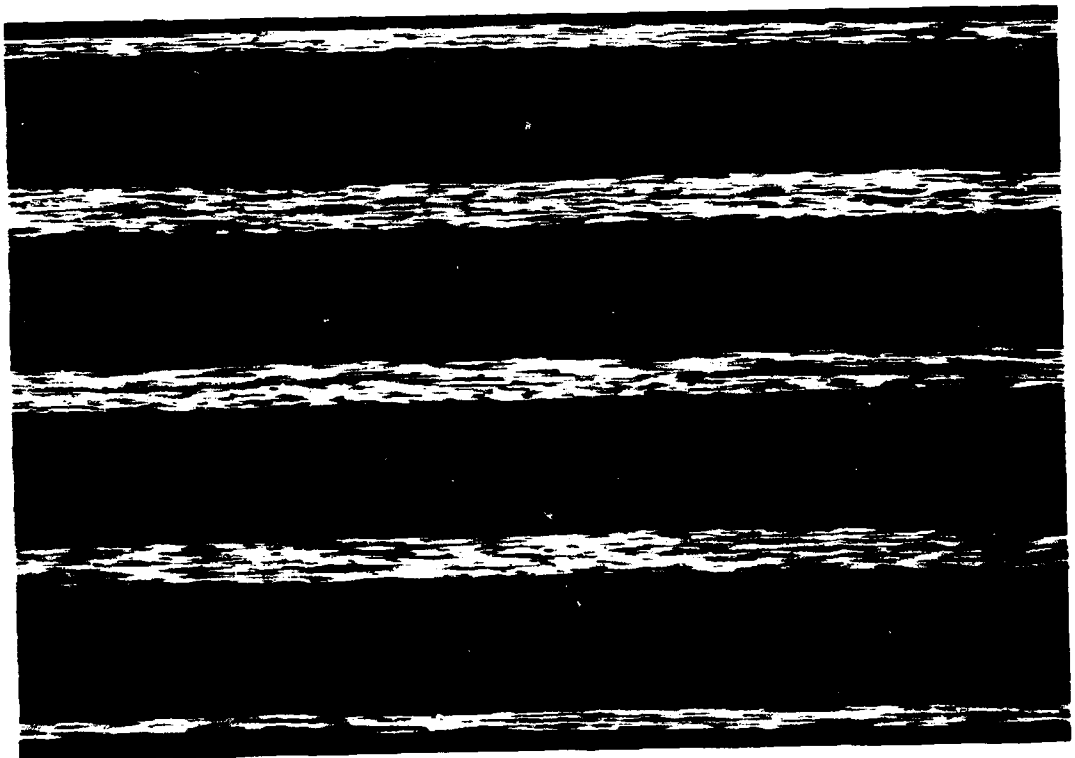
J30-18-1 10X



J30-18-2 25X

LOCATION: 2.54 IN. DAMAGE LENGTH: ONE TRANS PLY CRACK

J30-19-1 10X



J30-19-2 25X

LOCATION: 2.64 IN. DAMAGE LENGTH: No DAMAGE

APPENDIX H

Comparison of Damage as Determined by Holscan Ultrasonic C-Scan and DIB Enhanced X-ray

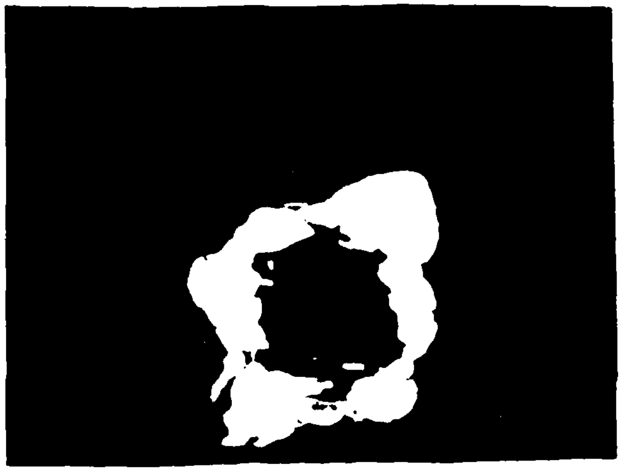


FIGURE H1: SPECIMEN NO. EB-14 N = 4,000 CYCLES

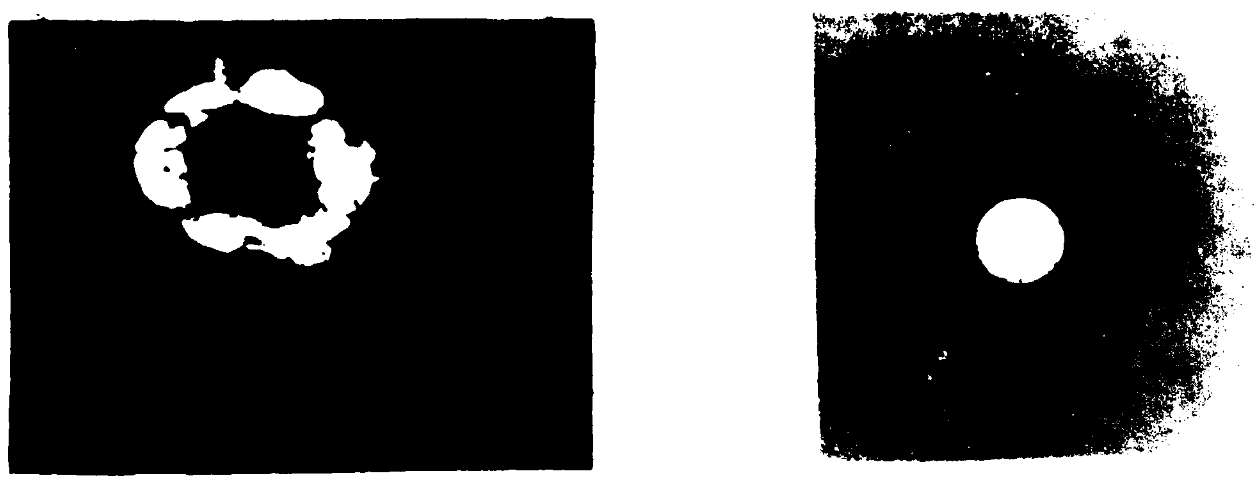


FIGURE H2: **SPECIMEN NO.** IA-5 **N = 4,000 CYCLES**
24-PLY

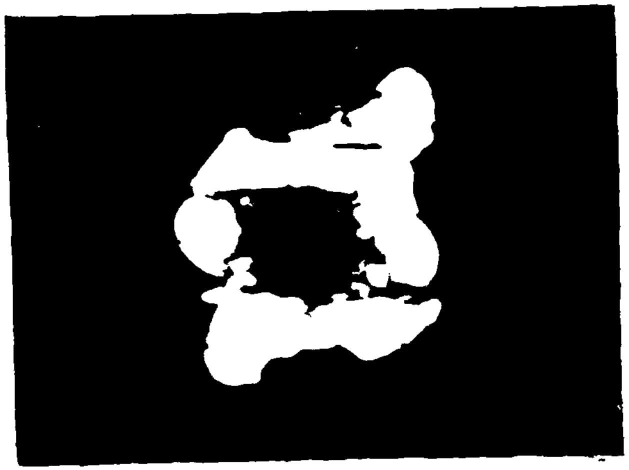


FIGURE H3: SPECIMEN NO. FA-6 N = 8,000 CYCLES
24-PLY

FIGURE H4: SPECIMEN NO. HA-8 N = 12,000 CYCLES

24-PLY

FIGURE H5: SPECIMEN NO. GC-23 N = 20,000 CYCLES

24-PLY

FIGURE H6: SPECIMEN NO. 0A-4 N = 1,000 CYCLES

32-PLY

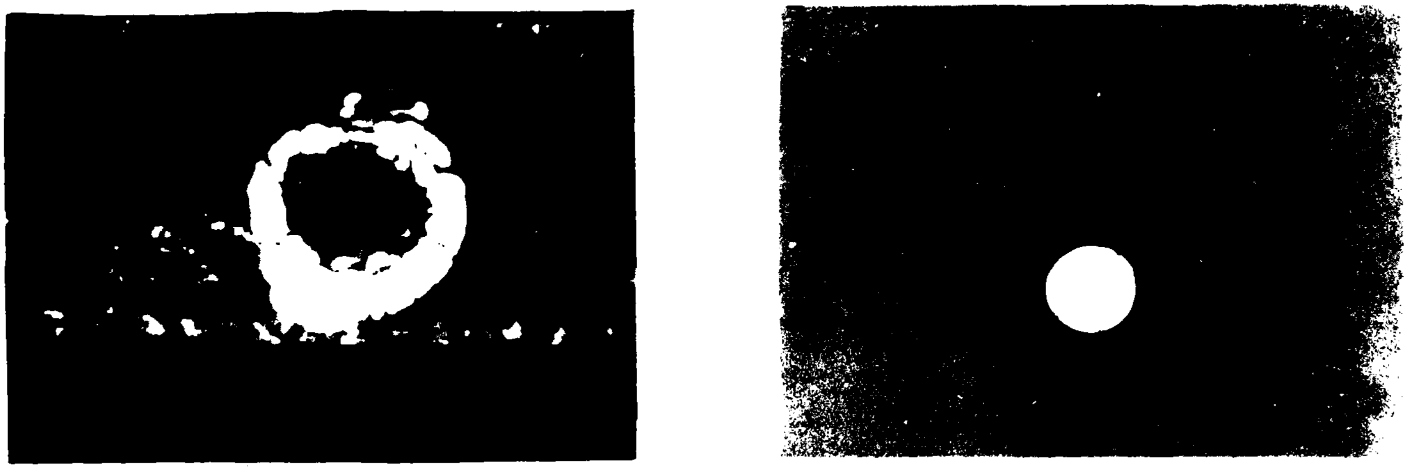


FIGURE H7: SPECIMEN NO. RC-29 N = 1,000 CYCLES

32-PLY

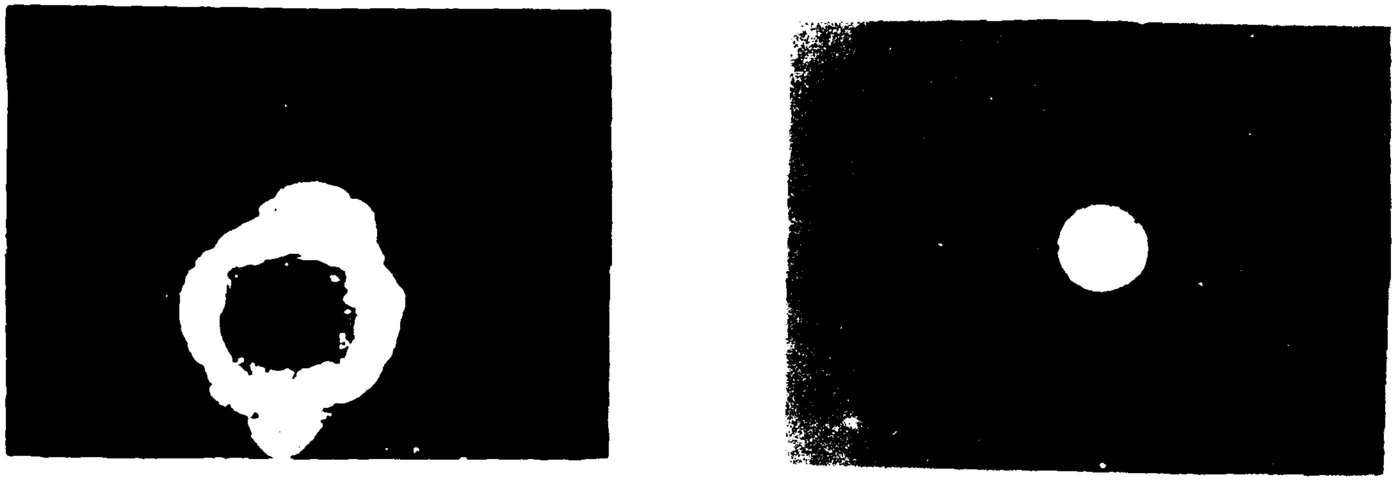


FIGURE H8: SPECIMEN NO. RB-19 N = 5,000 CYCLES

32-PLY

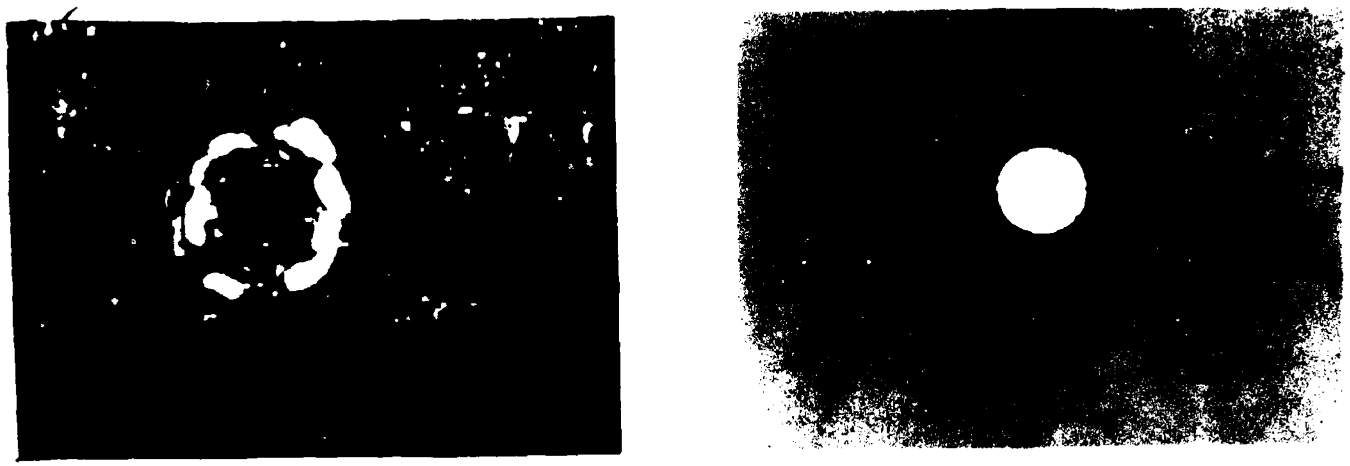


FIGURE H9: SPECIMEN NO. PC-21 N = 10,000 CYCLES

32-PLY

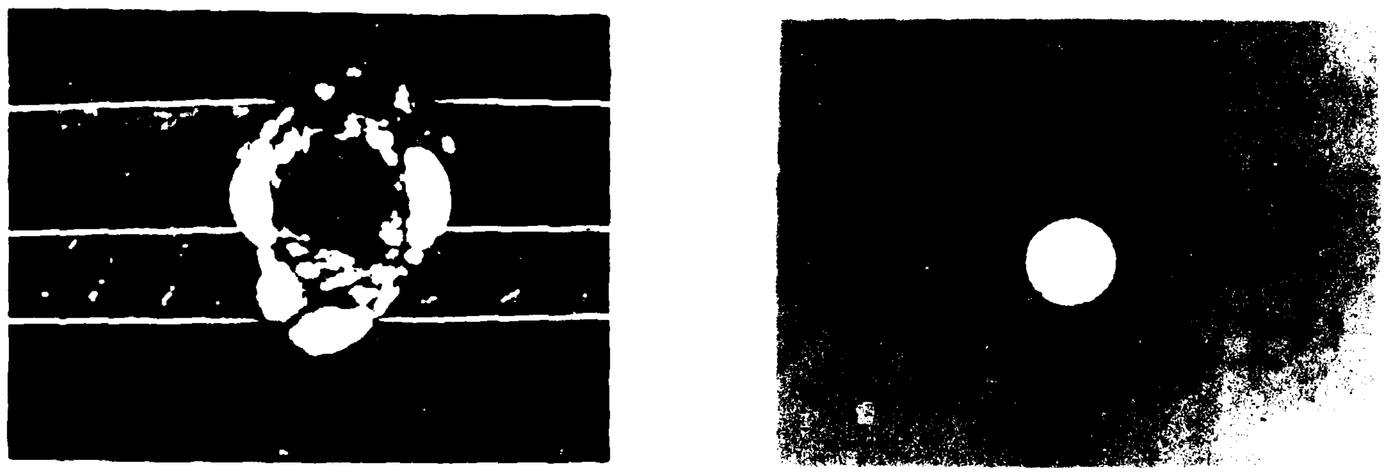
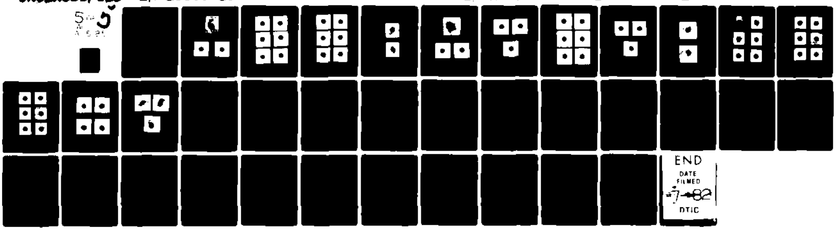


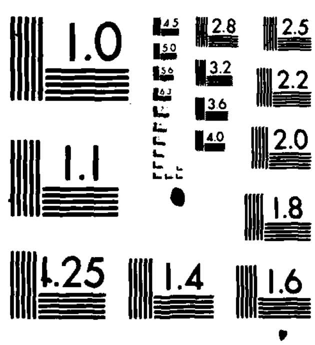
FIGURE H10: SPECIMEN NO. QC-24 N = 28,000 CYCLES

32-PLY

AD-A115 185 LOCKHEED-CALIFORNIA CO BURBANK F/G 11/4
ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC--ETC(U)
JUL 81 K N LAURAITIS, J T RYDER, D E PETTIT F33615-77-C-3084
UNCLASSIFIED LR-28360-19 AFWAL-TR-79-3095-VOL-3 NL



11518



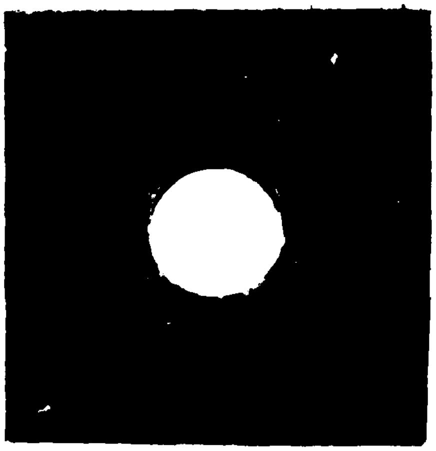
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX I

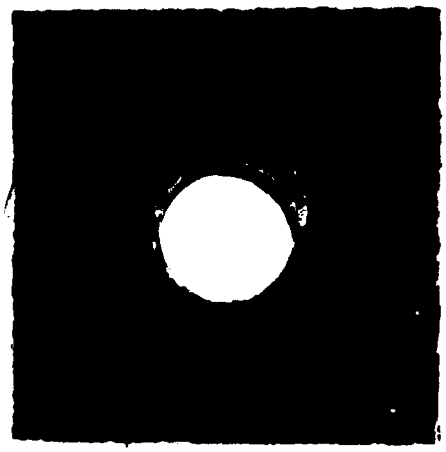
Damage on Individual Layers of

Specimens Deplied after Fatigue Cycling

I-5-1
PLY 1 0°

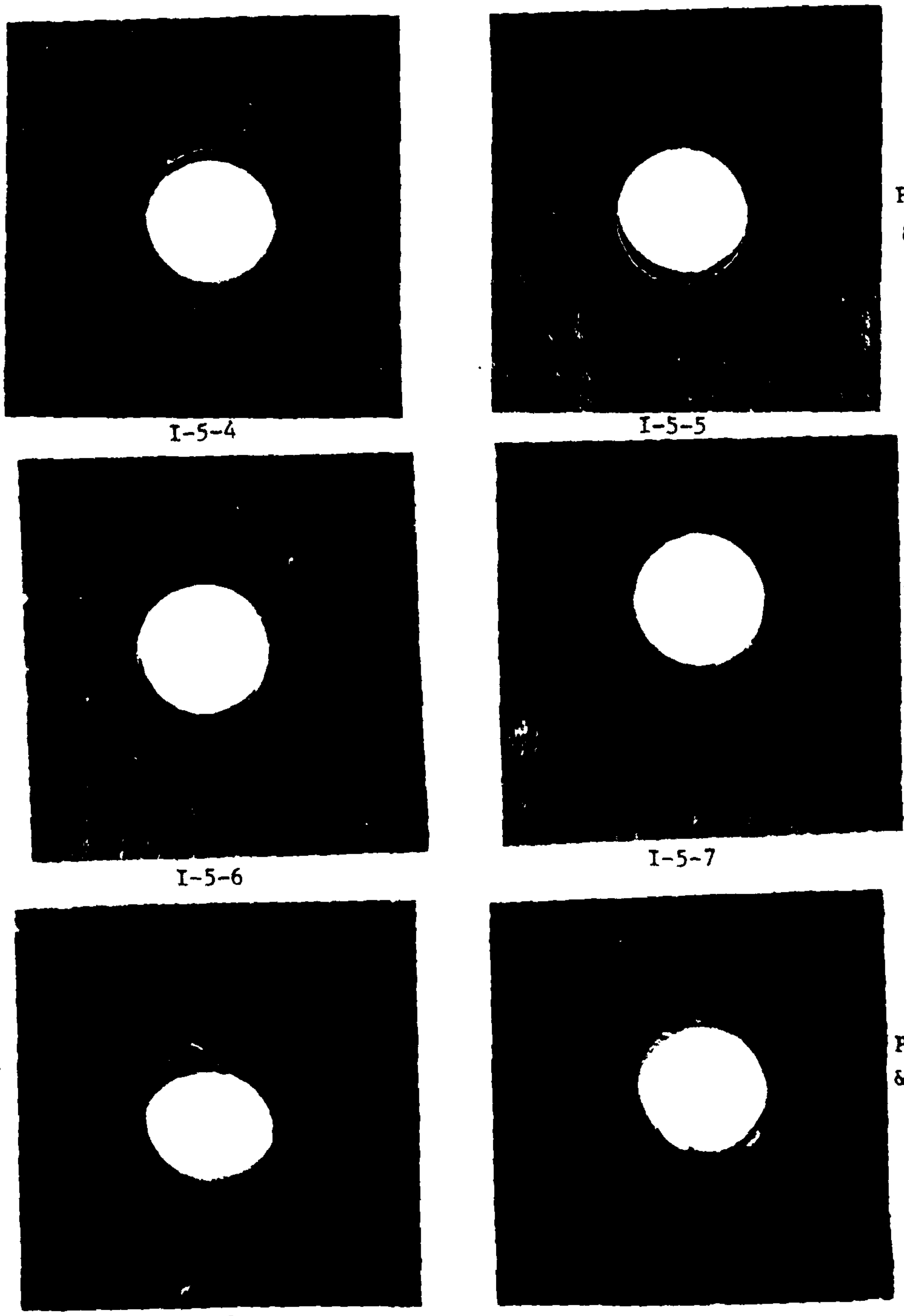


I-5-2
PLY 2 45°



I-5-3
PLIES 3 & 4, 0°

Figure IIa: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles (Plies 1 - 3)



PLY 5 -45°

PLIES 6 & 7, 0°

I-5-4

I-5-5

PLY 8 45°

PLIES 9 & 10, 0°

I-5-6

I-5-7

PLY 11 0°

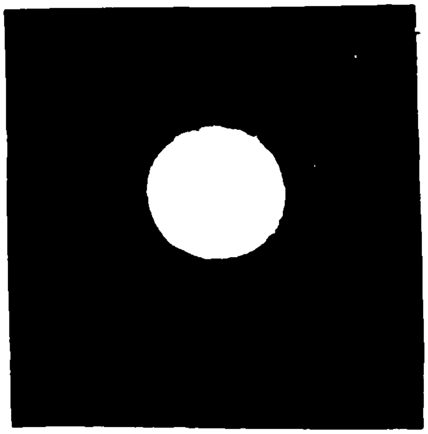
PLIES 12 & 13, 0°

I-5-8

I-5-9

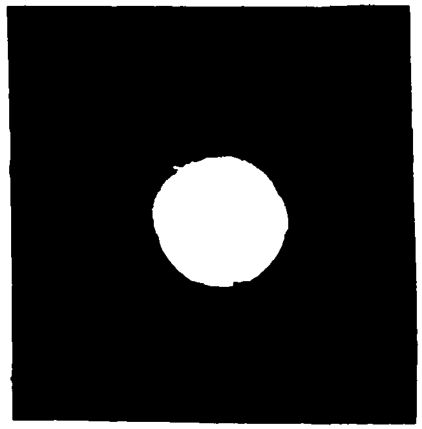
Figure IIb: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles (Plies 4 - 9)

PLY 14
-45°



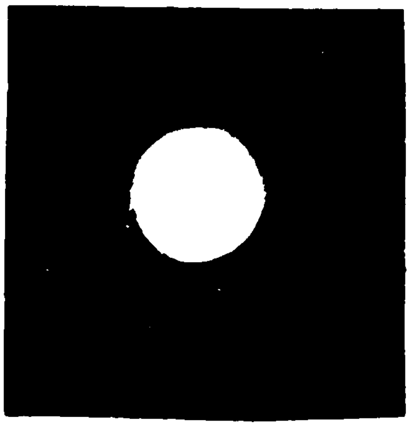
I-5-10

PLIES 15
& 16, 0°



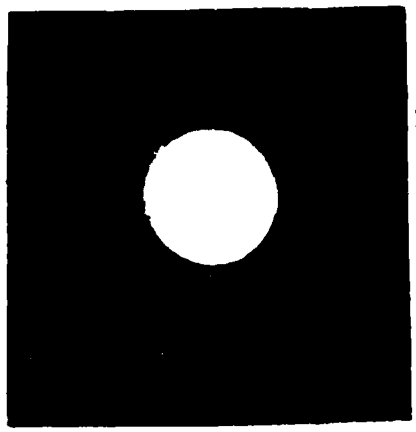
I-5-11

PLY 17
45°



I-5-12

PLIES 18
& 19, 0°

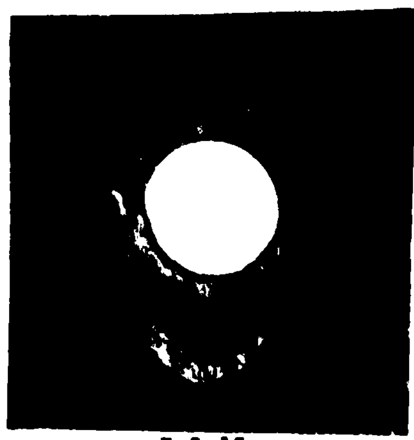


I-5-13

PLY 20
-45°

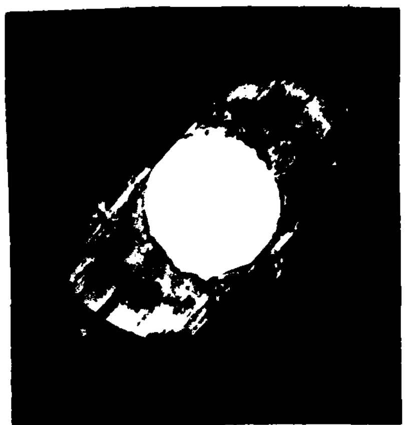
I-5-14

PLIES 21
& 22, 0°



I-5-15

Figure IIc: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles
(Plies 10 - 15)

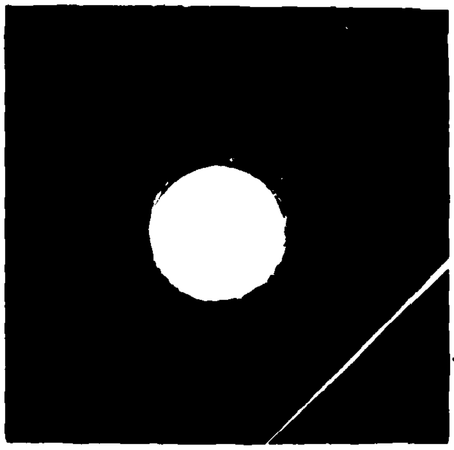


I-5-16
PLY 23, 45°

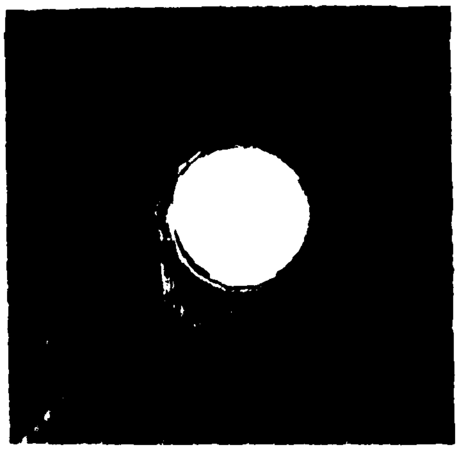
I-5-17
PLY 24, 0°

Figure IId: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles (Plies 15 - 17)

H-8-1
PLY 1, 0°

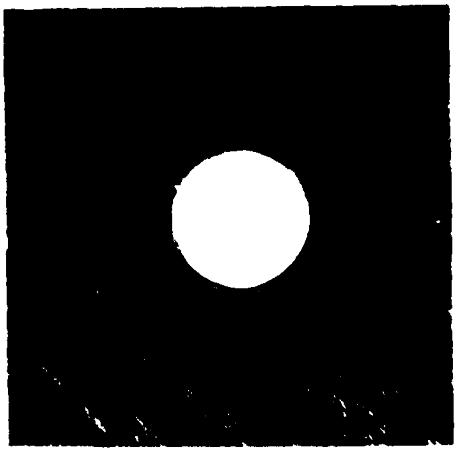


H-8-2
PLY 2, 45°

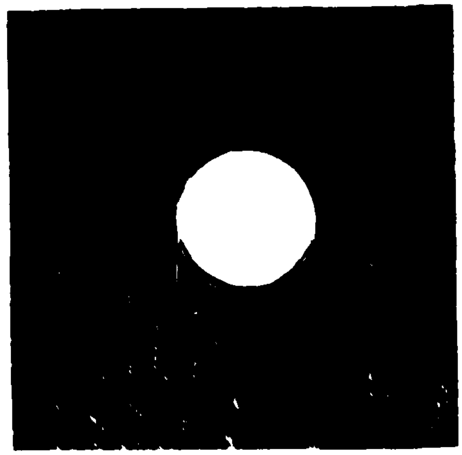


H-8-3
PLIES 3 & 4, 0°

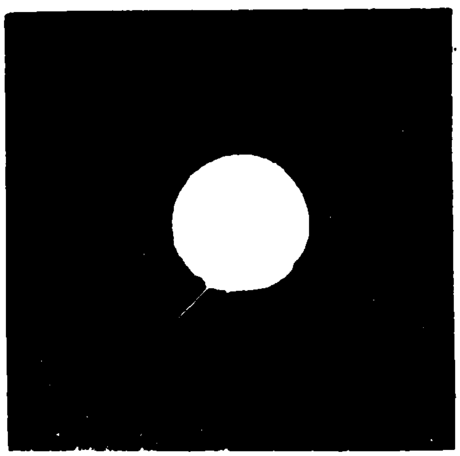
Figure I2a: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles (Plies 1 - 3)



H-8-4
PLY 5, -45°



H-8-5
PLIES 6 & 7, 0°



H-8-6
PLY 8, 45°

Figure I2b: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles (Plies 4 - 6)

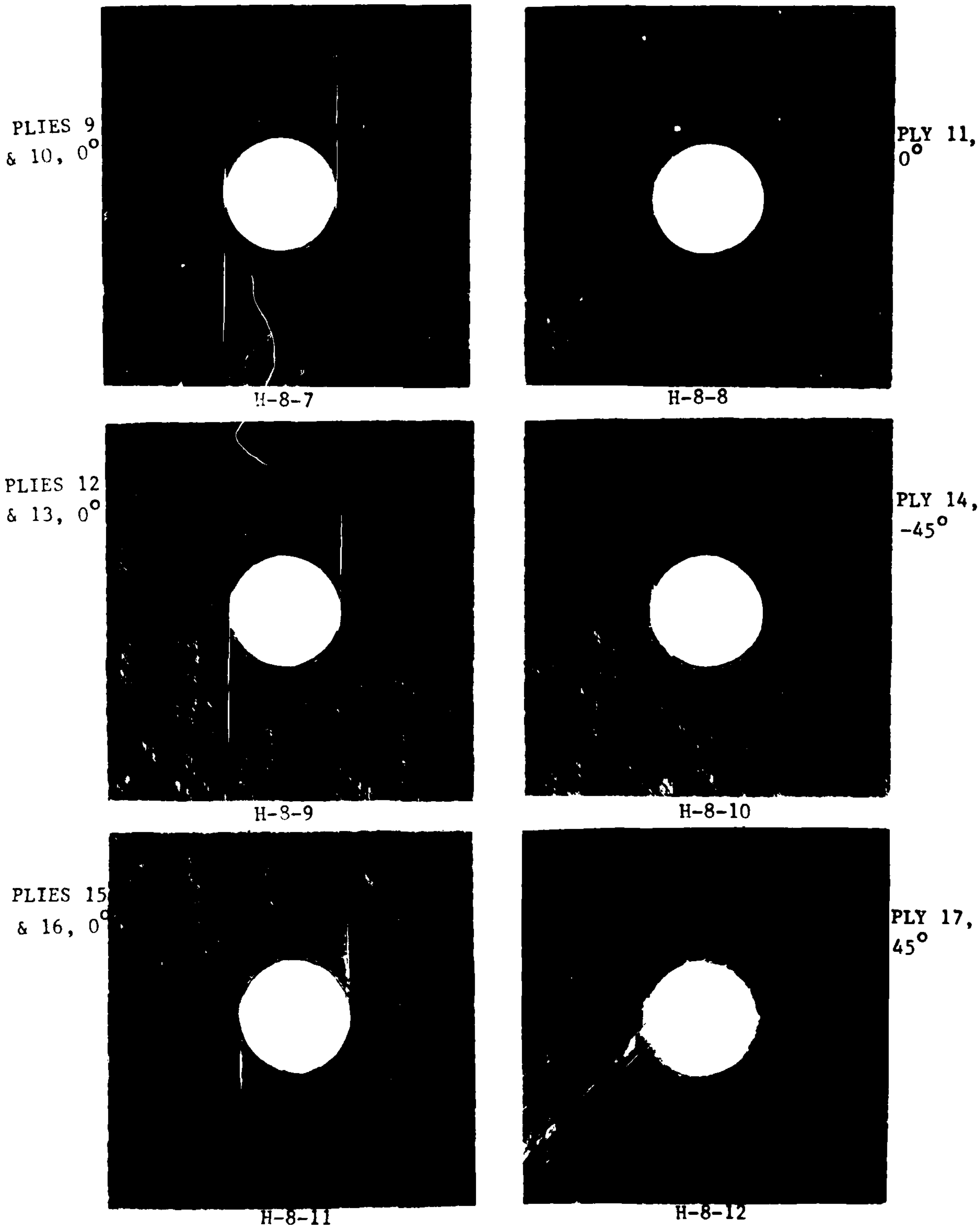
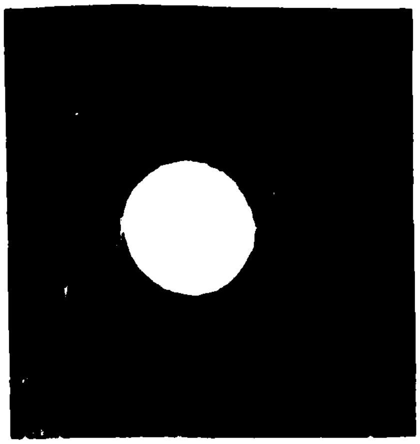


Figure I2c: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles (Plies 7 - 12)

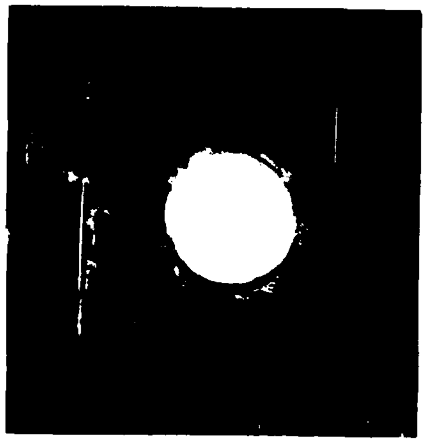


H-8-13

PLIES 18 & 19, 0°

H -8-14

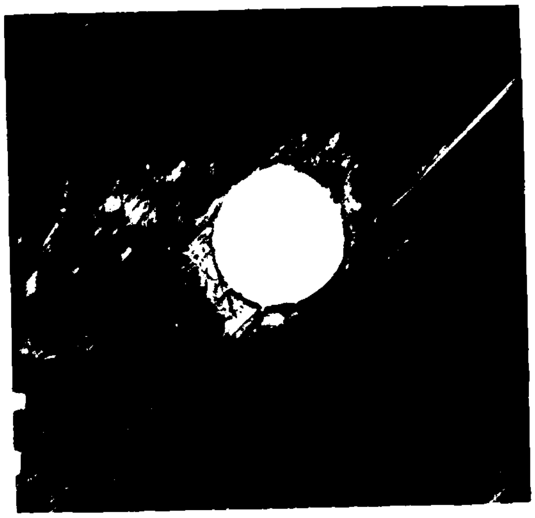
PLY 20, -45°



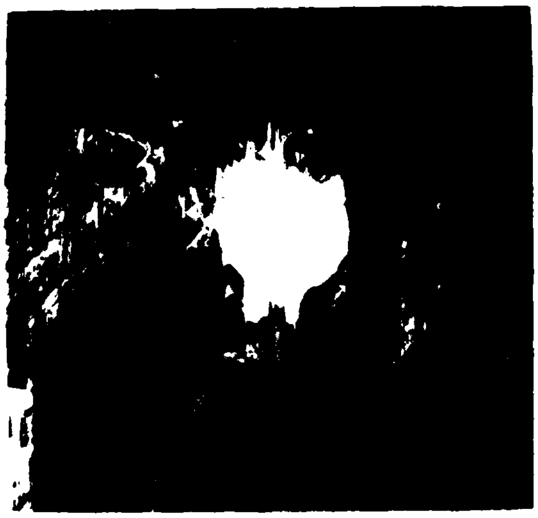
H-8-15

PLIES 21 & 22, 0°

Figure I2d: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles (Plies 13 - 15)

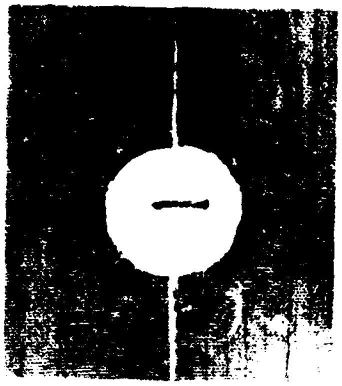


PLY 23, 45^{o}



PLY 24, 0^{o}

Figure I2e: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles
(Plies 16 - 17)

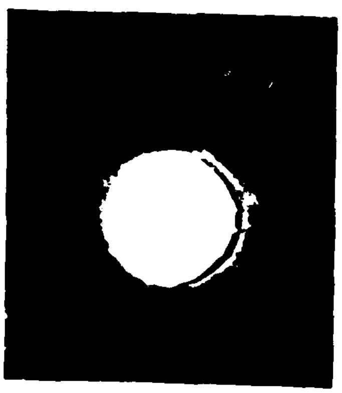


Q-4-1
PLY 1, 0^{o}

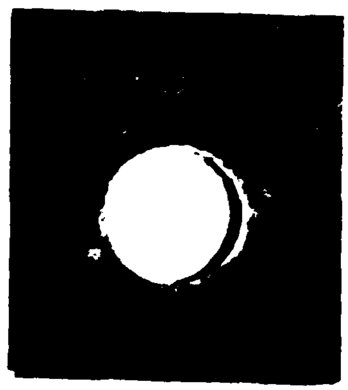
Q-4-2
PLY 2, 45^{o}

Q-4-3
PLY 3, 90^{o}

Q-4-4
PLIES 4 & 5, -45^{o}



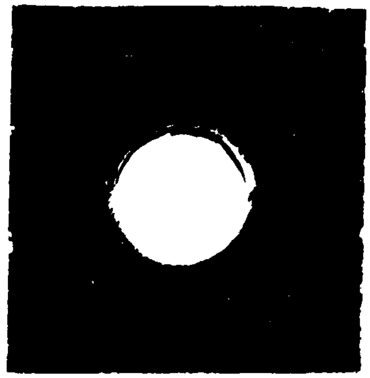
Q-4-5
PLY 6, 90^{o}



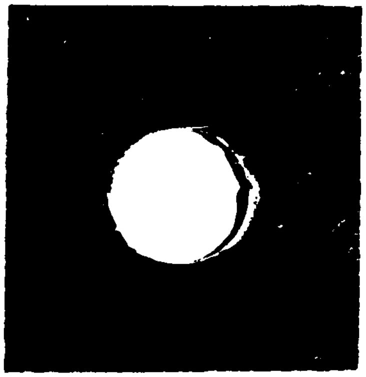
Q-4-6
PLY 7, 45^{o}

Figure I3a: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles (Plies 1 - 6)

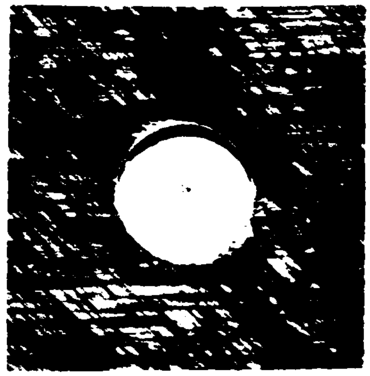
Q-4-7
PLIES 3 & 9, 0°



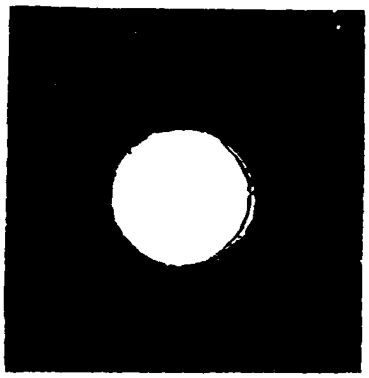
Q-4-8
PLY 10, 45°



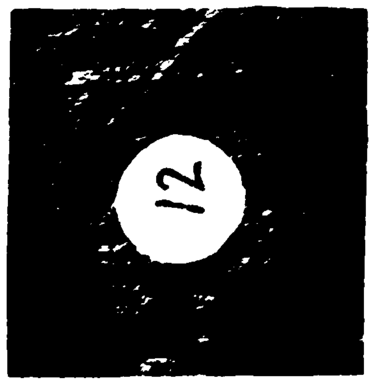
Q-4-9
PLY 11, 90°



Q-4-10
PLIES 12 & 13, -45°

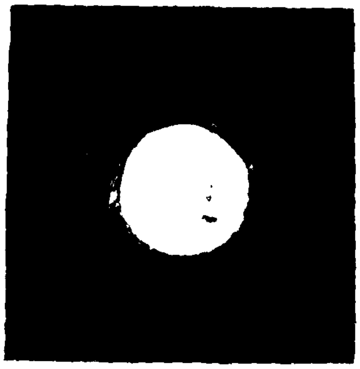


Q-4-11
PLY 14, 90°

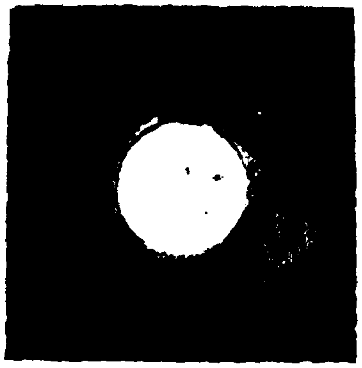


Q-4-12
PLY 15, 45°

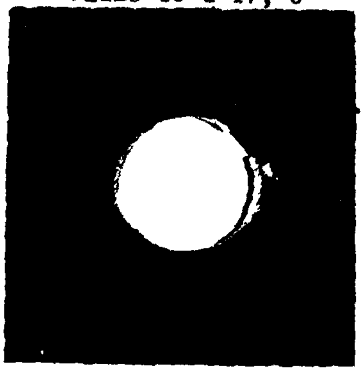
Figure I3b: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles (Plies 7 - 12)



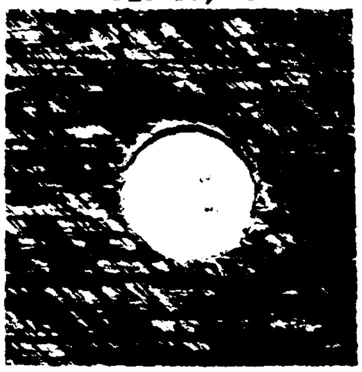
Q-4-13
PLIES 16 & 17, 0°



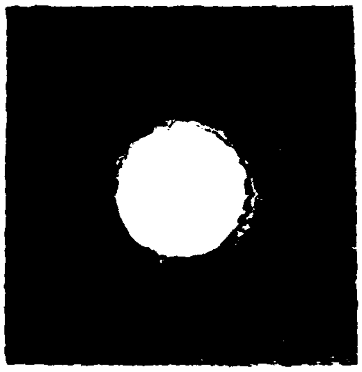
Q-4-14
PLY 18, 45°



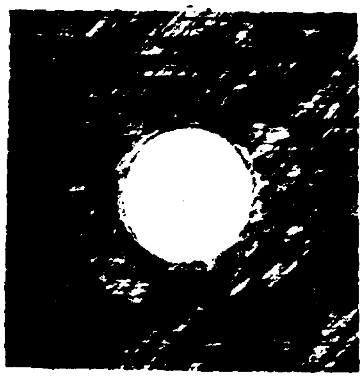
Q-4-15
PLY 19, 90°



Q-4-16
PLIES 20 & 21, -45°

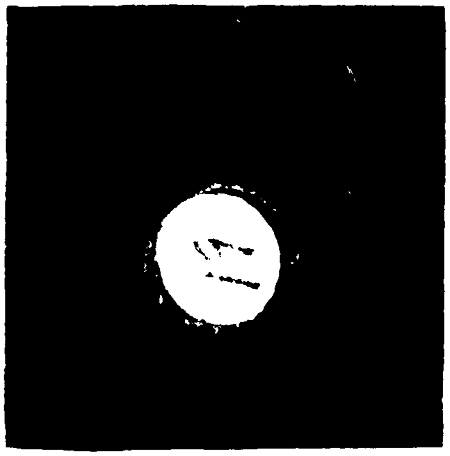


Q-4-17
PLY 22, 90°



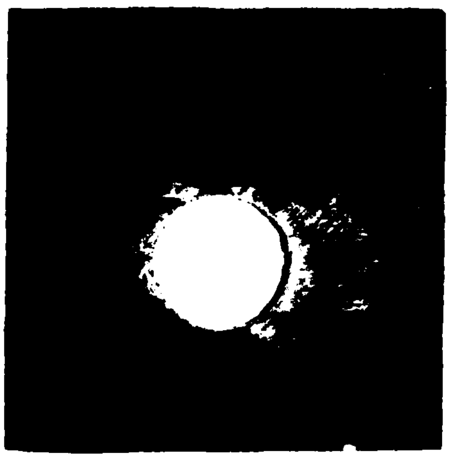
Q-4-18
PLY 23, 45°

Figure I3c: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles
(Plies 13 - 18)

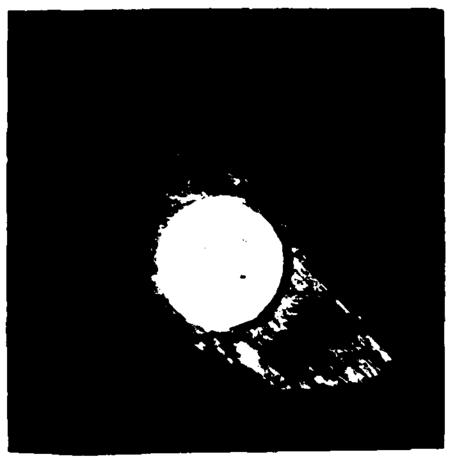


Q-4-19
PLIES 24 & 25, 0°

Q-4-20
PLY 26, 45°

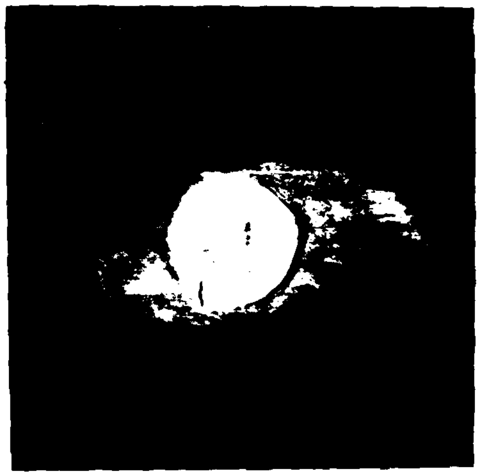


Q-4-21
PLY 27, 90°

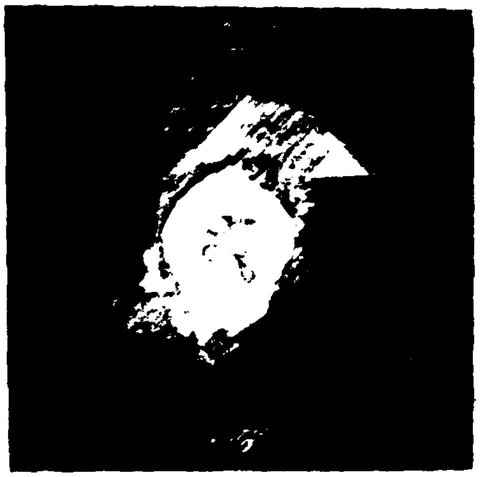


Q-4-22
PLIES 28 & 29, -45°

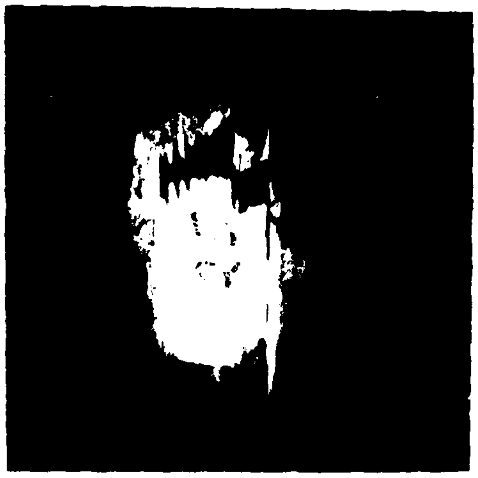
Figure I3d: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles
(Plies 19 - 22)



Q-4-23
PLY 30, 90°



Q-4-24
PLY 31, 45°



Q-4-25
PLY 32, 0°

Figure I3e: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles (Plies 23 - 25)

APPENDIX J

Statistical Analysis of Panel Variability

APPENDIX J

STATISTICAL ANALYSIS OF PANEL VARIABILITY

Due to the large number of specimens required for Task II, nine panels of each laminate type were fabricated. Considerable care was taken to produce panels under nearly identical conditions. All foreseeable variables were evaluated and specimens not meeting strict tolerance requirements were discarded as discussed in Volume I. The Task II static data were evaluated using several statistical procedures to determine whether the nine panel samples can be assumed to have come from the same population. Static data were normalized on the mean for each group of tests outlined in Test Plan Items 1-4, 6, 7 and 9 (See Table II of Vol. II). These results are presented in rank order by panel in Tables J1 and J2. The Wald-Wolfowitz[J1] test which determines whether two samples come from populations having *identical cumulative distribution functions* was performed for the 24-ply and 32-ply panel data sets.

The two series of data points from 24-ply panels A and D, having the lowest and highest means, respectively were pooled in rank order. If the strength value was from panel A, a 0 was entered, if from panel D, a 1. This resulted in the following array for the combined 34 data points.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	1

29	30	31	32	33	34
1	1	1	1	1	1

If $/u - \bar{u}/ \geq \sigma_u \; t_{\alpha/2}$, the hypothesis that the two samples come from populations having identical cumulative distribution functions (c.d.f's) is rejected at the α level; where u is the number of runs and $\bar{u}$ and σ_u^2 are the mean and variance of u respectively. For this case $/u - \bar{u}/ = 5.76$ and $\sigma_u t_{\alpha/2} = 5.55$. Therefore, the hypothesis is rejected at the 5% risk of error.

Table J1 Normalized Static Data[a] Rank Ordered By Panel for the 24-Ply Laminate - Task II

PANEL IDENTIFICATIONS:

	A	B	C	D	E	F	G	H	I
1.	0.813	0.932	0.927	0.928	0.837	0.870	0.897	0.837	0.925
2.	0.871	0.974	0.967	0.931	0.890	0.893	0.939	0.901	0.953
3.	0.915	0.981	0.968	0.932	0.933	0.893	0.947	0.910	0.955
4.	0.923	0.986	0.971	0.955	0.960	0.919	0.960	0.911	0.957
5.	0.962	0.987	0.975	0.991	0.964	0.943	0.984	0.947	0.975
6.	0.968	0.996	0.978	1.000	0.976	0.977	0.986	0.955	0.989
7.	0.968	1.011	0.986	1.009	0.983	0.980	0.986	0.964	0.993
8.	0.973	1.014	0.989	1.021	0.995	0.990	0.992	0.965	0.994
9.	0.975	1.016	0.992	1.070	0.999	0.995	0.994	1.018	1.008
10.	0.980	1.018	0.994	1.071	1.010	0.997	0.997	1.019	1.011
11.	0.990	1.022	1.009	1.073	1.011	1.014	1.000	1.034	1.014
12.	0.993	1.025	1.012	1.075	1.020	1.016	1.007	1.077	1.017
13.	0.999	1.033	1.019	1.087	1.033	1.024	1.018	1.174	1.018
14.	1.002	1.044	1.057	1.100	1.039	1.030	1.040		1.019
15.	1.013	1.065	1.067	1.144	1.071	1.035	1.048		1.038
16.	1.014	1.083	1.104		1.094	1.046	1.050		1.091
17.	1.020		1.140		1.126	1.062	1.052		
18.	1.034					1.062	1.065		
19.	1.035					1.110	1.076		
20.						1.132	1.114		
$\overline{X}$	0.971	1.012	1.009	1.026	0.997	0.999	1.008	0.978	0.997
SD	0.056	0.037	0.054	0.069	0.071	0.070	0.052	0.087	0.040
CV%	5.81	3.61	5.38	6.71	7.08	7.01	5.13	8.92	3.97

a = Includes all test data from Task II Test Plan Items 1-4, 6, 7 and 9 (See Table II of Vol. II)

NOTE: $\overline{X}$ = Mean, SD = Standard Deviation, CV% = Coef. of Var. %

Table J2 Normalized Static Data[a] Rank Ordered By Panel for the 32-Ply Laminate - Task II

PANEL IDENTIFICATIONS:

	J	K	L	M	N	P	Q	R	S
1.	0.883	0.947	0.882	0.878	0.782	0.927	0.913	0.904	0.857
2.	0.897	0.953	0.937	0.898	0.918	0.967	0.927	0.919	0.920
3.	0.919	0.960	0.956	0.938	0.934	0.972	0.942	0.923	0.924
4.	0.928	0.962	0.969	0.953	0.939	0.976	0.945	0.929	0.939
5.	0.939	0.965	0.972	0.954	0.949	0.983	0.947	0.933	0.954
6.	0.953	0.976	0.977	0.961	0.958	0.985	0.963	0.943	0.954
7.	0.965	0.977	0.978	0.971	0.960	0.995	0.964	0.948	0.956
8.	0.988	0.980	0.979	0.987	0.965	0.995	0.965	0.964	0.986
9.	0.993	0.989	1.006	0.987	0.979	1.006	0.968	0.964	0.989
10.	0.998	0.990	1.008	0.997	0.981	1.007	0.968	0.983	0.990
11.	0.999	0.991	1.009	1.008	0.984	1.019	0.995	0.987	0.991
12.	1.003	0.997	1.026	1.028	0.985	1.031	0.999	1.006	0.992
13.	1.009	1.004	1.030	1.059	1.001	1.039	1.007	1.007	1.000
14.	1.015	1.008	1.030	1.065	1.002	1.044	1.018	1.019	1.006
15.	1.019	1.009	1.035	1.068	1.004	1.050	1.059	1.031	1.009
16.	1.050	1.012	1.055	1.085	1.008	1.051	1.063	1.035	1.012
17.	1.053	1.018	1.061	1.102	1.014	1.087	1.064	1.049	1.038
18.	1.073	1.025	1.062	1.157	1.016	1.091	1.079	1.085	1.053
19.	1.076	1.043	1.080	1.176	1.045	1.120	1.082	1.117	
20.		1.049			1.062	1.156	1.168	1.154	
21.		1.144			1.072				
22.		1.192			1.140				
$\overline{X}$	C.987	1.009	1.003	1.014	0.986	1.025	1.002	0.995	0.976
SD	0.056	0.059	0.049	0.081	0.068	0.056	0.065	0.069	0.047
CV%	5.72	5.83	4.92	8.01	6.92	5.50	6.52	6.89	4.80

a = Includes all test data from Task II Test Plan Items 1-4, 6, 7 and 9 (See Table II of Vol. II)

NOTE: $\overline{X}$ = Mean, SD = Standard Deviation, CV% = Coef. of Var. %

However, the hypothesis cannot be rejected at the same level when the test is performed on the second highest (B) and second lowest (H) panels.

Performance of the Wald-Wolfowitz test on the 32-ply panels having the lowest (S) and highest (P) means yields the following array for the combined 38 data points:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	0	1	0	1	0	0	1	1

29	30	31	32	33	34	35	36	37	38
0	1	1	1	1	0	1	1	1	1

where a 0 was entered if the value came from panel S and 1 if from D. Here $/u - \bar{u}/ = 3.95$ and $\sigma_u t_{\alpha/2} = 5.94$. Hence, the hypothesis that the samples have identical c.d.f.s cannot be rejected for a risk of error of 5%. For the 32-ply panels, then, it appears likely that the strength data for all of the panels belong to the same population.

Since 24-ply panels A and D appeared to have different c.d.f's several additional tests were performed.

Applying the Chi-squared test to samples A and D indicates that there is a high probability (at $\alpha = 0.05$) the distributions are normal. Thus the F-test and T-test were then applied.

The quantity F is the ratio of the two sample variances,

$$F = S_A^2 / S_D^2$$

If the variances of samples A and D are identical at a significance level of $\alpha = 0.05$, F should be between the boundaries defined by $F_{0.975}$ and $1/F_{0.975}$, for $N_A - 1$ and $N_D - 1$ degrees of freedom. F does lie in this interval since $F = 0.670$, $1/F_{0.975} = 0.37$ and $F_{0.975} = 2.88$. Thus the variances can be assumed to be the same within 0.05 risk of error. This indicates

the two samples may belong to the same population, i.e. have the same scatter or dispersion.

The T-test was used to determine whether the means differ significantly. The absolute differences between the means is calculated by:

$$D_{\bar{x}} = /\bar{x}_A - \bar{x}_D/$$

If the means do not differ, $D_{\bar{x}}$ should not exceed u where

$$u = t_{0.975}\, S_P\sqrt{\frac{n_A + n_D}{n_A\, n_D}}$$

for $\alpha = 0.05$. For this case $D_{\bar{x}} = 0.055$ and $u = 0.0438$. Since $D_{\bar{x}} > u$ there is reason to believe samples might not be from the same population.

Based on these three tests, Wald-Wolfowitz, F-test and T-test the statement cannot be made that panel A and D data have the same cumulative distribution functions within a 0.05 risk of error.

This does not necessarily mean that the samples are from different populations although that possibility is definitely suggested. The many assumptions implicit in this type of statistical evaluation must be considered. No attempt was made to include fatigue data because the failure modes differ. However, all static data including tension, compression at high and low strain rates and residual strength data were normalized and combined. This in itself is a questionable procedure. Variables affecting stability under compression loading will not necessarily influence tension strength similarly especially for different strain rates and damage sizes. Data were pooled in order to obtain an adequate sample size to perform some evaluation of panel variability. If the data pooling were acceptable, it appears that except for the 24-ply panels A & D, all other panels are statistically identical. In fact, if the 24-ply panels were ranked by mean strength from low to high (A, H, E,

I, F, G, C, B, D) all adjacent panels would be identical. The panels form a smooth distribution with A and D at the tails. Thus a single "bad" panel cannot be identified.

APPENDIX K

DISCUSSION OF WEIBULL FUNCTION

AND PARAMETER ESTIMATION PROCEDURES

APPENDIX K

K.1 GENERAL DISCUSSION OF WEIBULL FUNCTION

In Weibull's representation of the statistics of fatigue, there are two random variates at each stress test condition. The first of these variates is the ordered sequence of the numbers of cycles to failure for each test result, n_i:

$$n_i: (n_1, n_2, n_3 \ . \ . \ . \ . \ n_N)$$

The second random variate, x, is continuous and is the argument of the Weibull survivorship function, or probability of survival, expressed as

$$P(x) = \exp\ [-((x-e)/(v-e))^k], \qquad \text{(K1)}$$

where

$$x \geq e,\ v \geq e,\ k > 0,\ P(e) = 1,\ P(v) = 1/\exp(1)$$

The connection between the random variates, n_i and x, is entirely empirical. In practice, numerical procedures are used to derive the three Weibull parameters k, e, and v by means of the approximation:

$$P(x) = 1 - i/N \text{ when } x = n_i, \qquad \text{(K2)}$$

or

$$P(x) = 1 - i/(N + 1).$$

For Equation K1 , the mean of the sample set is given by [K1]:

$$\bar{x} = e + (v-e)\,\Gamma(1 + 1/k) \qquad \text{(K3)}$$

the median by:

$$\breve{x} = e + (v-e)(\log_e 2)^{1/k} \quad \text{(K4)}$$

and the mode by:

$$\tilde{x} = e + (v-e)(1-1/k)^{1/k} \quad \text{(K5)}$$

where $\Gamma(\ )$ indicates the Gamma function.

During the past twenty-five years, a number of names have been applied to the parameters. In general, parameters e an v are considered as scale parameters or factors and the exponent k as a shape parameter. The term threshold parameter is usually applied to parameter e and the term characteristic value to v. In analysis of composite data, k is frequently denoted by α and v by $\hat{F}$. The scale parameter, e, is often referred to as the minimum life estimate. With this choice of words, e is suggested on physical grounds to be $e \geq 0$. Many authors have reasoned further that since $e \ll n_i$, $i = 1, 2, 3, \ldots N$, the Weibull survivorship function can be appropriately reduced to dependence on two parameters, k and v, with $e = 0$ arbitrarily. An argument against this practice will be described in this section.

The influence of the shape parameter k can be explained as follows. Define a reduced variate Z as:

$$Z = (x-e)/(v-e),\ Z \geq 0, \text{ dimensionless,} \quad \text{(K6)}$$

and express the probability of survival function as:

$$P(x) = \exp\left|-Z^k\right|,\ k > 0, \quad \text{(K7)}$$

where $P(Z) = 1/\exp(1)$ when $Z=1$

and $P(Z) = 1$ when $Z = 0$, for all k,

If $k < 1$, this is sometimes interpreted as implying that the material develops resistance to fatigue as the number of load cycles is increased. If $k = 1$, the Weibull survivorship function reduces to the constant failure rate relation commonly used in reliability studies. If $k > 1$, one can inquire whether the test material experiences progressive damage as numbers of load cycles are increased.

Figure K1 illustrates the manner in which P(Z) is dependent on the shape parameter k for the range of the reduced variate Z from zero to two. Empirical evidence does not support the interpretation that k might be a smoothly increasing function of stress amplitude. For practical purposes, in the case of structural fatigue, the region of Figure K1 of most interest to designers is bounded as follows:

(a) Above by the limit $P(Z) = 1.0$
(b) Below by the median $P(Z) = 0.5$
(c) On the left by the curve $P(Z) = \exp[-Z]$
(d) On the right by the curve $P(Z) = \exp[-Z^{10}]$.

K.2 WEIBULL ANALYSIS PROCEDURES

There are three principal procedures which have been used to determine the Weibull parameters (k, e, and v) for a given data set. These are: the moment estimation (ME) method; the maximum likelihood estimation (MLE) procedure; and some form of the linear regression (LR) procedure. All three methods are also used to determine the unknown parameters of other types of fitting functions. The ME method principally consists of equating several population moments (equal to the number of unknown parameters) to the sample

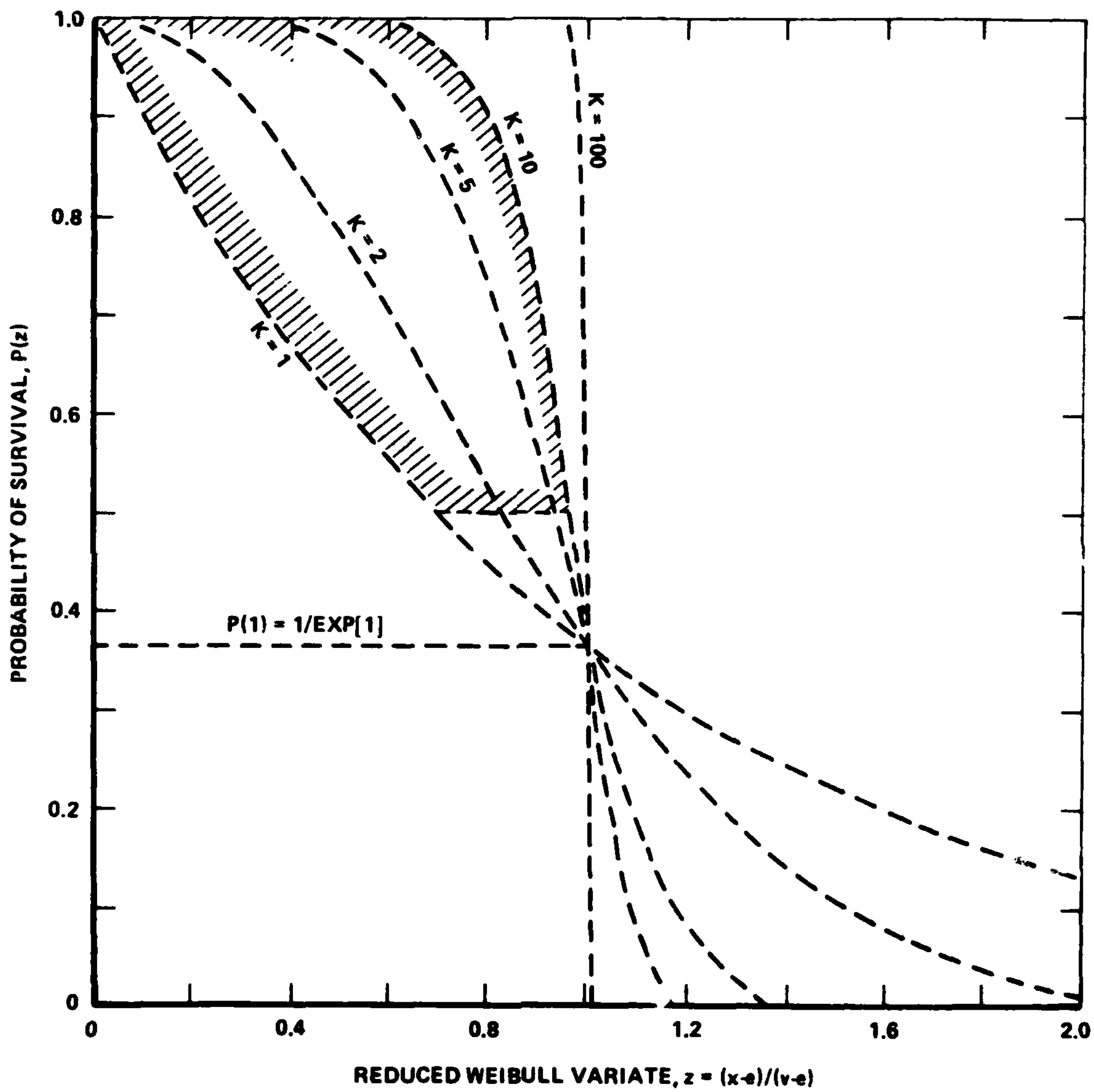


Figure K1 - Influence of shape parameter k on probability of survival

moments. The MLE method consists of setting the partial derivatives of the logarithm of P(X), with respect to the parameters sought, equal to zero. In the LR procedure, the Weibull survivorship function is reduced to a linear equation. For the LR method, the solution for a two-parameter Weibull function is straightforward, but in the three-parameter case the solution is found by optimization of the correlation coefficient or by matching the sample skewness coefficient.

When one of the above described procedures was originally selected[K2] for analyzing graphite/epoxy composite strength and fatigue data, consideration was given to two thoughts. First, how well does the resultant Weibull survivorship function represent the original data set? Second, what, if any, extrapolative potential exists for the resultant function? Consideration of these two questions led to the selection of the LR procedure. The reasons for this selection will be described in detail along with references to recent work which supports the original choice.

Both the ME and MLE methods require homogeneous samples. The reason for this requirement is that in the ME procedure the Weibull density function is integrated while in the MLE procedure, partial derivatives of the function are obtained. In this program, requirement of homogeneity was not assumed, a priori, to be necessarily met by sample information obtained from fracture data of composites. A procedure was desired which would be sensitive to the possible existence of multicomponent strength and fatigue life data. Such a requirement appears to be met by a LR procedure[K3]. The ME method can result in significant errors in estimation of k, e, and v[K3] and such errors increase as k increases. In the case of two-parameters, errors in estimation of k and v increase linearly with the true value of e (assumed to be zero) and can be greater than 100% when $e \geq v$[K3]. For the MLE procedure, three difficulties are encountered. First, the MLE solution of a data set is often a local maximum, but is not necessarily the maximum likelihood estimate[K1-K7]. Weibull and Weibull[K3] found in a study of 300 random samples

of 10 and 20 points each that approximately half of the estimates were not the maximum likelihood estimate, but were local maximums. Second, valid data sets can occur for which convergent solutions are not forthcoming, particularly for three parameter solutions[K7]. Third, if a given data set which actually belongs to a three-parameter Weibull population is assumed to be a two-parameter population ($e = 0$), the estimates of k and v can be significantly higher than their true values[K3].

As previously alluded to in the analysis of graphite/epoxy composite data, the parameter e is often set equal to zero. This practice greatly simplifies the mathematics especially for MLE procedures; however, there are strong objections against such a practice[K1,K3,K7]. These have already been discussed with reference to the ME and MLE procedures and are based upon the statistical error induced by the practice of setting $e = 0$. In summary, the three-parameter Weibull fit can be shown to fit the actual data set better than the two-parameter[K2,K3,K7]. However, objections against the three-parameter Weibull fitting procedure are often raised upon the grounds that the parameter e may be found to have a negative value, particularly for a fatigue data set. The objection is thus raised that actual coupons can not have a finite probability of failure when the applied load is zero. Setting e equal to zero solves this problem. Setting e equal to zero is principally related to the question of the extrapolative capability of the Weibull function for graphite/epoxy composite fracture data.

Setting $e = 0$ results in the probability of survival, P_s, being equal to 1 when no load is applied to a coupon. While this is a reasonable expectation, the accuracy of fit in the range of the data is often sacrificed. At the same time, the resultant extrapolative estimates of strength and fatigue life at $P_s > 0.90$ may still be intolerably conservative. Therefore, in many cases by setting $e = 0$ little may be gained, and much lost. This problem is most critical for fatigue life data.

The problem of correctly extrapolating composite fatigue data is presently one of conjecture. This is due to three deficiencies: 1) lack of large laboratory data sets for evaluating extrapolation from small subsets; 2) lack of experimental data which correlates laboratory coupon results with structural test results; 3) lack of field service experience. Therefore, while e should be greater than or equal to zero if it is truly a threshold parameter, correct values can not be determined at this time. Thus, setting $e = 0$ reduces the accuracy of our calculated fit to the data set but most likely results in extrapolative predictions being too conversative.

A possible solution to these problems has been suggested by Bowie, Besari, and Trapp[K7] and will be discussed below. The resultant analytical solutions closely fit the data and avoid the problems of ME and MLE solution procedures. The resultant functions are not of extrapolative value, but this is not considered to be pertinent for comparison of data sets. Significant statistical analysis effort combined with extensive experimental investigations are needed before any extrapolative procedure can be developed and used with confidence. Hence, using a procedure which does not allow for extrapolation is not considered at the present time to be detrimental.

K.3 DESCRIPTION OF SELECTED ANALYSIS PROCEDURE

The particular form of Weibull analysis used in this report has been discussed in detail elsewhere[K7,K8]. Essentially, this procedure which consists of linear regression analysis in Z variate space, is similar to that used by Talreja[K3]. The analysis procedure used is described in this section.

In the analytic procedure used in this program, an initial estimate was made of the probability of survival based directly on the test results, in a staircase manner, $P(n_i)$, $i = 1, 2, 3, \ldots N$,

where

$$P(n_1) = 1-1/N$$
$$P(n_2) = 1-2/N$$
$$P(n_3) = 1-3/N$$
$$\vdots \qquad \vdots$$
$$P(n_N) = 1-N/N = 0.$$

The function $P(n_i) = 1 - i/N$ was selected instead of the alternate function, $P'(n_i) = 1 - i/(N+1)$. The difference $(P'(n_i) - P(n_i))$ diminishes as N increases. Thus for N equal to or greater than approximately 15, the difference is undetectable. However, if extrapolations to probability of survival in the range above 90% are to be attempted, the choice of $P(n_i)$ rather than $P'(n_i)$ as initial distribution is the more conservative approach[K8]. This is especially true for N less than 15.

With the above approach, the initial distribution is defined as:

$$P(n_i) = 1 - i/N$$

and
$$P(n_{i+1}) = 1 - i/N \text{ if } n_{i+1} = n_i$$

otherwise
$$P(n_{i+1}) = 1 - (i+1)/N$$

In most other analysis procedures, $P'(n_i) = 1 - i/(N+1)$ is selected as the initial description without regard to replication of the type: $n_{i+1} = n_i$. The choice of assigning the same initial probability to different coupons with the same n_i was considered appropriate because they do actually form a local mode, within the limits of testing accuracy, of the sample distribution obtained by experiment.

The appropriate variables of Equation K1 are found by forming N-1 relations:

$$
\begin{aligned}
P(n_1) &= 1-1/N = \exp\left[-((n_1-e)/(v-e))^k\right] \\
P(n_2) &= 1-2/N = \exp\left[-((n_2-e)/(v-e))^k\right] \\
&\vdots \\
P(n_N) &= 1-(N-1)/N = \exp\left[-((n_{N-1}-e)/(v-e))^k\right]
\end{aligned}
\tag{K8}
$$

The last relation for N is not used since $P(N) = 0$.

The parameters of Equation 1 were found by reducing the relationships of Equation 8 to the linear equation:

$$Y = bX+a \tag{K9}$$

The three-parameter Weibull linear equation is:

$$\left[-\ln P(X)\right]^{1/k} = bX+a,$$

where $e = -a/b$ (K10)

and $v = (1+be)/b.$

For the two-parameter Weibull function ($e = 0$), the linear equation is:

$$\ln(-\ln(p(X))) = b\ln(x) + a, \tag{K11}$$

where $k = b$

and $v = \exp(-a/b).$

A linear regression method is used to determine k, e, and v. The initial

order distribution is:

$$P(X_i) = 1-i/N_p, \; i = 1, 2, 3 \ldots N_p \tag{K12}$$

Regression coefficients are found by least square analysis of $N_p -1$ equations such as:

$$\left|-\ln\,(1-i/N_p)\right|^{1/k} = bX_i + a, \; i = 1, 2, 3 \ldots N_p-1. \tag{K13}$$

The sample correlation coefficient, R, is calculated as:

$$R = \frac{M \sum_{i=1}^{M} Y_i (aX_i + b) - \sum_{i=1}^{M} Y_i \sum_{i=1}^{M} (aX_i + b)}{\left[\left\{M \sum_{i=1}^{M} Y_i^{\,2} - \left(\sum_{i=1}^{M} Y_i\right)^2\right\}\left\{M \sum_{i=1}^{M} (aX_i + b)^2 - \left(\sum_{i=1}^{M} (aX_i + b)\right)^2\right\}\right]^{1/2}} \tag{K14}$$

where $M = N_p - 1$

The coefficients of linear regression and alternative correlation coefficient r are calculated by means of the following steps:

$$Sx = \left[\frac{M \sum_{i=1}^{M} X_i^2 - \left(\sum_{i=1}^{M} X_i\right)^2}{M\,(M-1)}\right]^{1/2}$$

$$Sy = \left[\frac{M \sum_{i}^{M} Y_i^2 - \left(\sum_{i=1}^{M} Y_i\right)^2}{M\,(M-1)}\right]^{1/2}$$

$$b = \frac{M\sum_{i=1}^{M} X_iY_i - \left(\sum_{i=1}^{M} X_i\right)\left(\sum_{i=1}^{M} Y_i\right)}{M\sum_{i=1}^{M} X_i^{\,2} - \left(\sum_{i=1}^{M} X_i\right)^2}$$

$$a = \left(\sum_{i=1}^{M} Y_i - b\sum_{i=1}^{M} X_i\right) \Big/ M$$

$$r = b\ sx/sy$$

The standard deviation of the linear regression is calculated by means of the *expression:*

$$s = \left[\frac{(M-1)}{(M-2)}\, Sy^2 + (1 - r^2)\right]^{1/2}$$

The values of k, e, and v are found by iterating on 1/k in Equation K13 and maximizing R in Equation K14. An alternative procedure would be to match the sample skewness to the Weibull function skewness by iteration of 1/k. The coefficient of skewness is given by:

$$c.o.s = \frac{\Gamma(1+3/k) - 3\Gamma(1+1/k)\Gamma(1+2/k) + 2\Gamma^3(1+1/k)}{(\Gamma(1+2/k) - \Gamma^2(1+1/k))^{3/2}} \qquad \text{(K15)}$$

and recalling that $\Gamma(\ \ )$ denotes the Gamma function.

There are two primary difficulties with the method employed. First, the resultant Weibull functions could be used to imply that in some three-para-

meter cases and at a given extrapolation, high probability of survival (P_S > 0.95), fatigue life decreases as applied stress amplitude decreases. Second, in the case of two-parameter analysis, probability of survival functions tend to predict overly conservative extrapolated fatigue lives, particularly at low applied stress amplitudes. Both of these difficulties refer to the extrapolative capability of the resultant functions. This is not considered a problem for comparing the data sets, and as discussed in Section K.2, extrapolation of the data does not appear to be presently feasible.

K.4 ALTERNATIVE PROCEDURES

Two other procedures are available for analyzing fracture data. They are the Standardized Variable Estimation (SVE) method[K3] and the Modified Double Expotential Function (MDEF) method[K7].

In the SVE method[K3] the standardized variable Z is defined as in Equation K6 for a Weibull survivorship function or as:

$$Z = \frac{X-e}{v} \tag{K16}$$

for a Weibull probability of failure function. Thus, as mentioned in Section K.1, the order statistics Z_i are independent of e and v and depend only on the shape parameter k. The expected value, EZ_i, median, MZ_i, and variance, VZ_i, of the order statistic Z_i have been derived by Lieblein. The characteristic values of Z_i depend only on the sample size, N, and the shape parameter, k[K3]. From Equation K16, we obtainK3:

$$X_i = e + v\ EZ_i \tag{K17}$$

or

$$X_i = e + v\ MA_i. \tag{K18}$$

Equations K17 and K18 can be solved by linear regression. The shape

parameter k is the value for which the correlation coefficient is a maximum[K3]. The parameters e and v are found as the X_i - intercept and slope of the best fit line[K3]. If the sample data belong to different populations, this will result in the (X_i, EZ_i) and (X_i, MZ_i) scattering about different straight lines[K3].

Talreja[K3] found that the SVE method provided accurate estimates of k, e, and v, for low values of k. At higher k values, the method often gives negative estimates of e. The procedure gave more accurate estimates of the parameters than the ME and MLE methods[K3].

The MDEF is based upon the double exponential function of Gumbel[K1]. In this procedure[K7], for a set of sample fatigue lives, N_P, the initial distribution is defined by:

$$P(X_i) = 1 - i/(N_P + 1) \tag{K19}$$

and P(x) by:

$$P(X) = 1 - \text{Exp}\,[-\text{Exp}[-\alpha_o\,(X-u)]. \tag{K20}$$

For lives greater than u, the above function is used as described by Gumbel [K1]. For lives less than u, α is a function of the life, X, where:

$$\alpha(X) = \alpha_o \left[\frac{\ln u - \ln X_o}{\ln X - \ln X_o}\right] \tag{B21}$$

The parameter X_o is defined as the threshold fatigue life. For $X \leq X_o$, P_S is defined as equal to unity. The modified double exponential function (MDEF) can be solved by ME, MLE, or LR procedures. The best procedure appeared to be linear regression[K7]. The MDEF function was found to not only fit the sample data with high correlations, but to provide procedures for exploration of data extrapolation accuracy[K7].

REFERENCES
APPENDIX J AND K

J1 Burington, R. S. and May, D. C., Handbook of Probability and Statistics with Tables, 2nd Edition, McGraw-Hill, New York, New York, 1970.

K1 Gumbell, E.J., Statistics of Extremes, Columbia University Press, New York, 1958.

K2 Ryder, J.T., and Walker, E.K., "Ascertainment of the Effect of Compressive Loading on the Fatigue Lifetime of Graphite Epoxy Laminates for Structural Applications", AFML-TR-76-241, December 1976.

K3 Talreja, R., "Estimation of Weibull Parameters for Composite Material Strength and Fatigue Life Data," ASTM STP 723, Fatigue of Fibrous Composite Materials, American Society for Testing and Materials, 1981, pp. 291-311.

K4 Weibull, W. and Weibull, G.W., "New Aspects and Methods of Statistical Analysis of Test Data with Special Reference to the Normal, the Log Normal and the Weibull Distributions," Part I and II, FOA Report D20045-DB, Defense Research Institute, Stockholm, Denmark, June, 1977.

K5 Antle, C.E. and Klimko, L.A., "Choice of Model for Reliability Studies and Related Topics II", ARL-73-0121, AD 772775, 1973.

K6 Harter, H.L. and Moore, A.H., "Maximum Likelihood Estimation of the Parameters of Gamma and Weibull Populations from Complete and Censored Data", Technometrics, Vol. 1, No. 4, 1965, pp. 639-643.

K7 Bowie, G.E., Besari, M.S., and Trapp, W. J., "Experimental Mechanics: Development of Methods for Numerical Analysis of Composite Fatigue Data", Lockheed-California Company Report LR 27981, January, 1977.

K8 Bowie, G.E., Pettit, D. E., Ryder, J.T., and Krupp, W.E., "NDI Life Analysis Interface", Lockheed-California Company Report LR 27013, September 1974.

*U.S.Government Printing Office: 1982 — 559-005/4060

ILMED

8